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PB-285 707

Effects of Thermal Treatment of Sludge on Municipal Wastewater Treatment Costs

Culp, Wesner, Culp - Clean Water Consultants, El Dorado Hills, CA

Prepared for

Municipal Environmental Research Lab, Cincinnati, Ohio Wastewater Research Div

Jun 78

United States
Environmental Protection
Agency

Research and Development

Municipal Environmental Research
Laboratory
Cincinnati OH 45268

EPA-600/2-78-073
June 1978

PB 285 707

EPA

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TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO.
EPA-600/2-78-073

2.

3. ENT'S ACCESSION NO.
PB285707

4. TITLE AND SUBTITLE
EFFECTS OF THERMAL TREATMENT OF SLUDGE ON MUNICIPAL WASTEWATER TREATMENT COSTS

5. REPORT DATE
June 1978 (Issuing Date)

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
Lewis J. Ewing, Jr., Howard H. Almgren, and Russell L. Culp

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Culp/Wesner/Culp
Clean Water Consultants
El Dorado Hills, California 95630

10. PROGRAM ELEMENT NO.
1BC611, Task A/26

11. CONTRACT/~~GRANT~~ NO.
68-03-2186

12. SPONSORING AGENCY NAME AND ADDRESS
Municipal Environmental Research Laboratory--Cin., OH
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

13. TYPE OF REPORT AND PERIOD COVERED
Final

14. SPONSORING AGENCY CODE
EPA/600/14

15. SUPPLEMENTARY NOTES
Project Officer: Francis L. Evans, III 513/684-7610

16. ABSTRACT

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The data presented provide means of estimating costs and operating and maintenance requirements for a variety of facilities on an average basis, but do not supplant the need for detailed study of local conditions or recognition of changing design requirements in preparing estimates for specific applications.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Heat treatment, Sludge, Sludge disposal, Cost engineering, Cost estimates, Waste treatment	Thermal conditioning, Sludge thermal treatment	13B

18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 120
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE A06 - A01

☆ U.S. GOVERNMENT PRINTING OFFICE: 1978– 757-140/1325

EPA-600/2-78-073
June 1978

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Contract No. 68-03-2186

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our national environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

This report presents data from which construction costs and operating and maintenance requirements may be estimated for thermal treatment of municipal wastewater sludge. The use of the information contained in this report facilitates making cost analyses for alternative solutions to proposed projects.

Francis T. Mayo, Director
Municipal Environmental Research
Laboratory

ABSTRACT

Data for estimating average construction costs and operation and maintenance requirements are presented for (1) thermal treatment of municipal wastewater sludges (2) handling, treatment, and disposal of the strong liquor generated, and (3) controlling odors produced. Size ranges covered are treatment plants of 1 to 100 mgd, and sludge handling facilities of 1 to 100 tons per day. Estimating data are included for many separate process functions associated with thermal treatment of sludge, processing of the sidestreams, and control of odors produced. Where possible, cost components are presented in a manner that will allow adjustment to fluctuating costs for labor, materials, and energy.

The data presented provide means of estimating costs and operating and maintenance requirements for a variety of facilities on an average basis, but they do not supplant the need for detailed study of local conditions or recognition of changing design requirements in preparing estimates for specific applications.

This report was submitted in partial fulfillment of Contract Number 68-03-2186, under sponsorship of the U. S. Environmental Protection Agency. The report covers the period August 1975 to July 1977, and work was completed as of September 1977.

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ACKNOWLEDGMENTS

Culp, Wesner, Culp, Clean Water Consultants, are grateful to the owners and operators of municipal thermal treatment plants, equipment manufacturers, consulting engineers, and the U. S. Environmental Protection Agency for data and information necessary for the preparation of this report.

SECTION I

INTRODUCTION

Thermal treatment of sludges produced in municipal wastewater treatment is used as a conditioning process. It involves heating sludge under pressure for short periods of time with or without the addition of air or oxygen. The process may serve a number of purposes by proper selection of temperature, contact time, and amount of air added. Where destruction of pathogenic organisms is required, the sludge may be pasteurized. To improve thickening or dewatering characteristics, the sludge may be heat treated or subjected to low, intermediate, or high degrees of wet air oxidation. With high oxidation, the amount of ash remaining is about the same as with conventional incineration; but wet air oxidation does not require preliminary dewatering or drying as do conventional combustion processes. Sludges containing only 1 percent solids may be processed, whereas a minimum of about 15 percent solids is required for economical incineration.*

By coagulating the solids and breaking down the gel structure of sludge, thermal treatment processes produce significant changes in the nature and composition of the sludge. Water that was tightly bound to raw sludge solids is released along with proteins, carbohydrates, and zoogleal slimes forming a dark brown cooking liquor. The liquor may be separated from the cooked solids by decanting, centrifuging, filtering, or draining on granular beds. Under some conditions of heat treatment, the end products are almost odorless; but under many other conditions, they may have a strong odor, sometimes described as a scorched coffee odor.

Liquor from thermal treatment of sludge contains high concentrations of materials that have been solubilized in the process, including BOD (biochemical oxygen demand), COD (chemical oxygen demand), ammonia, and phosphorus. As much as 30 percent of the COD may be nonbiodegradable in a 30-day period.

Although much is known about thermal treatment of wastewater sludges and the results that can be attained, cost data are fragmentary and often do not include information on the costs for handling, treating, and disposing of the strong liquor or for controlling odors produced. The impact of such costs on total treatment costs is relatively unknown. To ascertain the full and true costs of thermal treatment of sludge, this report collects and analyzes costs associated with the process from a number of operating installations.

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* The processing of a 1% sludge in an intermediate or high oxidation mode can be done autothermally, whereas, incineration of 15% solids sludge cake will require outside auxiliary fuel.

SECTION II

CONCLUSIONS AND RECOMMENDATIONS

1. Recommendations and observations based on field visits to 28 thermal treatment systems include:

   a. Pilot plant operation before design is desirable.

   b. The auxiliary units for which back-up should be provided include sludge feed pumps, grinders, air compressors, high pressure pumps, boiler waterfeed pumps, and boilers.

   c. Effluent grit removal from the sludge is essential.

   d. The treated sludge storage tank should be equipped with decanting facilities.

   e. Digestion before heat treatment is not desirable.

   f. Operating temperatures should be kept as low as possible consistent with adequate sludge conditioning.

   g. The lead operator for the thermal treatment system should have a good mechanical aptitude and be able to do frequent, routine preventive maintenance.

   h. The need to remove scale from heat exchangers is the most frequent reason for routine shutdowns of thermal treatment systems.

   i. High chloride wastewaters (i.e., in coastal areas where seawater intrusion may occur) require the use of especially corrosion resistant materials in the thermal treatment system.

   j. Odor problems are common and adequate control facilities should be used. The methods most commonly used for control of odors are high temperature incineration, adsorption on activated carbon, and chemical scrubbing.

   k. The BOD load imposed on the wastewater treatment plant by recycle of the liquors from the thermal treatment system can constitute 20 percent of the total influent BOD load. The recycle liquors usually impart a color to the final plant effluent and may significantly degrade the effluent quality if the wastewater treatment plant does not have adequate capacity to treat the recycle loads.

2. The following cost information directly related to the thermal treatment system was developed:

   a. Capital costs for thermal treatment systems vary from about $50,000/gpm of thermal treatment system capacity for a 10 gpm system to $10,000/gpm for a 200 gpm system. The higher unit cost for the smaller systems reduces the economic feasibility for small plants.*

   b. Typical fuel requirements are 900-1,000 Btu/gallon for thermal systems not practicing air addition and 300-600 Btu/gallon with air addition.

   c. Average electrical consumption averaged 22 Kwh/10^3 gallons for plants with air addition and 10 Kwh/10^3 gallons without air addition.

   d. Operation and maintenance labor constitutes a significant fraction of overall costs, ranging from 6,000 man-hours/year for a 10 gpm system to 20,000 man-hours/year for a 200 gpm system.

   e. Costs for materials and supplies range from $5,000/year for a 10 gpm system to $20,000/year for a 200 gpm system.

3. The following cost information related to indirect costs for handling and treating the recycle liquors was developed (based upon increasing the capacity of an existing activated sludge system to handle the recycle load):

   a. Increased capital costs primarily result from the need to increase aeration tank volume and air supply capabilities.

   b. Increased energy is required for added aeration needed to treat the recycled liquor.

   c. Increased labor is needed for maintaining and operating the added aeration capacity and related settling and pumping systems.

4. Costs for treating the off-gas from the thermal treatment system typically constitutes 5-10% of the total costs for thermal treatment. Carbon adsorption is the most costly technique for odor control. Incineration is economically attractive in the smaller plants and chemical scrubbing in the larger plants.

5. Based upon unit costs of $7/hr for labor, $0.03/Kwh for electricity, and $2.80/$10^6$ Btu and amortization of capital costs over 20 years at 7% interest, the following typical costs for heat treatment were determined (all costs are dollars/ton of dry solids processed):

---

* See Appendix B for a list of metric conversions.

Sludge	Construction Cost			O & M Cost			
Ton/Day	Direct	Indirect	Total	Direct	Indirect	Total	Total Cost
1	97.53	4.11	101.64	150.14	4.93	155.07	256.71
5	30.79	3.18	33.97	46.46	3.67	50.13	84.10
10	21.45	2.93	24.38	32.52	3.50	36.02	60.40
50	12.20	1.83	14.03	19.10	2.99	22.09	36.12
100	10.96	1.98	12.94	16.58	2.87	19.45	32.39

Cost curves are presented which enable evaluation of costs where other unit costs are appropriate.

6. The advantages of thermal treatment systems include:

   a. Conditions sludges so that they dewater more readily and more completely than when conditioned by other means. This provides a reduction in dewatering and incineration costs and may enable operation of a conditioning-dewatering-incineration system without the need for supplemental fuel.

   b. Can provide pasteurization of the sludge rendering it free of pathogenic organisms.

   c. Can provide oxidation of sludges without the preliminary dewatering required for incineration and with substantially reduced air pollution potential.

   d. Can provide reduction of sludges containing toxic materials which would render biological stabilization processes ineffective.

7. The disadvantages of thermal treatment systems include:

   a. Greater mechanical complexity than most systems that municipal treatment plant operators are familiar with. Operators are often reluctant to work on or around the high temperature-pressure equipment.

   b. Requires substantial operator attention and frequent maintenance. Many of the systems visited reported substantial downtime due to maintenance problems.

   c. Produces odorous off-gas that must be collected and deodorized before release.

   d. Transforms insoluble organic substances in the sludge into soluble materials which appear in a high strength cooking liquor. Recycle of this liquor to the wastewater treatment plant can degrade effluent quality if the plant does not have adequate capacity to handle the recycle load. Recycled liquor may also result in refractory organics appearing in the effluent causing color and increased COD levels.

e. At small scale the comparatively high cost of support equipment makes heat treatment facilities more costly to build than other sludge treatment plants. Operations are expensive because of the constant attention required by a skilled operator. Also, the necessary operational skill might not be available to a small plant.

SECTION III

TASK OBJECTIVE

The general objective of this study has been the procurement of organized information pertaining to the impact that thermal conditioning of sludge has on municipal wastewater treatment plant costs. The impact of costs associated with the handling and disposing of thermal process supernatant has been determined as well as the capital, operating, and maintenance costs associated with the thermal process. In some cases, where actual operating costs could not be obtained, engineering estimates have been made.

The objective of this task has not been to make a sanitary engineering appraisal of the advantages or disadvantages or any particular thermal treatment process for conditioning sludge, but was intended to be an independent survey of all the costs associated with the various processes commercially available for thermally conditioning those sludges normally generated during the treatment of municipal wastewater.

In pursuing the general task objective, there were a number of detailed objectives to be accomplished. Capital, operating, and maintenance cost information on the most frequently used thermal process designs in the United States were obtained first hand by surveys, plant visits, correspondence, and telephone contact. Since there is little information on the costs associated with handling and disposing of liquid and gaseous side streams from thermal conditioning processes, particular emphasis has been placed on this area. Cost data have been based preferentially on actual plant operating experience. Published cost data have been used only when it has been verified to represent facts accurately. In those instances where cost data were not available from construction or operation experience, engineering estimates have been made based on sound fundamentals. Where possible, costs have been developed for different-sized, similar type thermal systems to provide insight into scale-up economics. Information has been developed on the costs for handling the strong liquors produced by thermal treatment of sludge including: (1) direct recycle to the main plant, and (2) pretreatment prior to plant recycle. The costs for odor control of thermal process off-gases have been ascertained. The cost effects of heat treatment liquor recycle on plant effluent quality have been determined.

It was intended that plants practicing phosphorus removal by chemical addition be studied so that the impact of phosphorus-laden chemical sludges on thermal process costs could be analyzed and so that any impact of phosphorus-chemical laden thermal supernatant on the treatment plant could be evaluated. Very few plants practicing both phosphorus removal and thermal treatment were found and the data available from those plants were not sufficient to permit detailed analyses.

The temperature, pressure, and detention time of the thermal process affect several items of cost including: (1) operation and maintenance of the thermal process, (2) the size of the load recycled to the main plant in the strong liquor, and (3) the dewatering characteristics of the heat treated sludge.

The cost of air addition in thermal treatment has been investigated. In addition to the direct cost of compressing the air, there are other indirect considerations such as: (1) differences in heat transfer efficiencies, (2) materials of construction which must be used to resist increased corrosion tendencies in the presence of oxygen, and (3) differences in odor production, type of sludge, and strength of strong liquor recycled.

Because virtually all of the equipment for thermal treatment of sludge in the United States has been supplied in the past by Zimpro or BSP (Envirotech), this study deals almost exclusively with the processes and equipment used by these two manufacturers.

SECTION IV

STUDY PROCEDURE

LITERATURE REVIEW

A search was made of published information on thermal treatment of wastewater sludge and associated costs. Bibliographies were prepared on thermal treatment and on odor control. They appear at the end of this report.

CORRESPONDENCE

A list of thermal treatment installations was compiled from information supplied by equipment manufacturers. Letters requesting operating information were sent to all 43 cities and sewer districts which had been operating thermal plants for one year or more. Data were obtained in response to these requests from about 10 sources. Follow up letters to 20 of the original correspondents who did not answer produced only one reply. On the other hand, good response was obtained from follow-up letters seeking missing information from those who answered the original request for data.

FIELD VISITS

The best method for collecting the data needed in this task proved to be field visits to operating plants following advance arrangements with the city or sewering agency to do so. This method was by far the most productive. Although complete information on costs is just not available in some cases, a field visit makes it possible to determine this definitely, as well as to collect all of the data that are available and to view the installation first hand. First hand observation of plant operations yields information and understanding which cannot be gained in any other way.

A tabulation of the 28 plants visited and the type of thermal treatment equipment installed at each of them is given in Section VI of this report.

Visits were also made to the offices and manufacturing plant of Zimpro at Rothschild, Wisconsin and the offices of BSP at Menlo Park, California to gather background data and to learn which of their installations might yield the best cost records.

TELEPHONE CONTACTS

The telephone was used to make final arrangements for field visits and to fill information gaps in written submittals or in field data. It was also used to verify questionable data.

DATA ANALYSIS

The cost data collected in this survey were in terms of various calendar dates and from different geographical locations. By methods described in more detail later, these costs were transformed into national average costs as of March, 1975. This facilitates cost comparisons and makes the cost figures more useful in development of new projects. Wherever possible, labor costs for operation and maintenance have been expressed in terms of man-hours per year as well as in March, 1975 dollars. Graphical representations have been used to show dollar costs and man-hours of effort for various aspects of construction, operation, and maintenance of thermal systems. The graphs included in this report are shown in the List of Figures. Discussions which appear later describe in more detail the assumptions and methods used to develop individual graphs or curves.

SECTION V

THERMAL TREATMENT PROCESSES

GENERAL

As mentioned in the Introduction, sludges resulting from the treatment of municipal wastewaters may be subjected to high temperatures under pressure for any of several purposes such as destruction of pathogenic organisms, improvement of sludge dewatering, or, with air addition, partial or complete oxidation. Thermal treatment may also be used to process wastes containing toxic materials which prevent the use of biological methods.

Pasteurization

Heat treatment is a well known and effective method for destroying pathogenic organisms, and it has been applied successfully for disinfecting sludge. Pasteurization at 70°C (159°F) for 30 to 60 minutes will destroy pathogens in digested sludge. Under normal conditions of temperature and retention time used in low pressure oxidation, all pathogenic organisms are destroyed. Time and temperature are inversely related in heat sterilization; the higher the temperature, the shorter the required exposure time. For example, at 120°C (249°F) in a laboratory autoclave (compressed steam) it requires only 6 minutes to kill even very resistant spores.

An advantage of a sterile, non-infectious residue is that it can be used on land or disposed of without biological hazards to human health.

Sludge Conditioning

If the goal of thermal treatment goes beyond elimination of pathogens to conditioning of sludge for dewatering and reducing or eliminating chemical requirements, this can be done by increasing temperatures. To maintain reaction temperatures higher than the minimums used in Pasteurization it is necessary also to increase operating pressures in order to prevent flashing of the water to steam or burning.

The EPA Technology Transfer "Process Design Manual for Sludge Treatment and Disposal," (October 1974) includes the following discussion of sludge conditioning by heat treatment which is appropriate for quotation here:

> "In heat treatment, temperatures of from 300 to 500°F and pressures of 150 to 400 psig are attained for protracted periods. Significant changes in the nature and composition of wastewater sludges result. The effect of heat treatment has been ideally likened to syneresis, or the

breakdown of a gel into water and residual solids. Wastewater sludges are essentially cellular material. These cells contain intracellular gel and extracellular zoogleal slime with equal amounts of carbohydrate and protein. Heat treatment breaks open the cells and releases mainly proteinaceous protoplasm. It also breaks down the protein and zoogleal slime, producing a dark brown liquor consisting of soluble polypeptides, ammonia nitrogen, volatile acids, and carbohydrates. The solid material left behind is mineral matter and cell wall debris."

"Dewaterability is improved by the solubilizing and hydrolyzing of the smaller and more highly hydrated sludge particles which then end up in the cooking liquor. While analysis of this liquor from domestic wastewater sludges indicates the breakdown products are mostly organic acids, sugars, polysaccharides, amino acids, ammonia, etc., the exact composition of the liquor is not well defined."

"A review of reported analyses of liquor from the heat treatment of sludge gives the range of values shown: BOD_5 = 5,000 to 15,000 mg/l, COD = 10,000 to 30,000 mg/l, Ammonia = 500 to 700 mg/l, and Phosphorus as P = 150 to 200 mg/l. About 20 to 30 percent of the COD is not biodegradable in a 30-day period. The volume of cooking liquor from an activated sludge plant with heat treatment amounts to 0.75 to 1.0 percent of the wastewater flow. Based on BOD_5 and solids loadings, the liquor can represent 30 to 50 percent of the loading to the aeration system. The pH of cooking liquors is normally in the range of 4 to 5, which necessitates chemical neutralization and/or corrosion resistant equipment."

"Plant experiences have shown that the conditioning requirements and hence the performance achieved in thickening and dewatering processes are affected by the manner in which sludge is treated."

The same degree of improvement in filterability and settleability of activated sludge, humus, digested sludge, and mixtures of activated and primary sludges can, within limits, be accomplished by various combinations of time and temperature. Long-time and low temperature treatment is usually the most economical. For a given holding time, lower temperatures are required to reduce the specific resistance for filtration of humus and digested sludge than for activated sludge.

"Over-cooking" can lead to an increase in specific resistance due to breakdown of fibrous material which would otherwise aid filtration. Crude fiber degradation is nearly linear with increase in temperature and oxidation. Both specific resistance and the quality of heat treatment liquor can be accurately estimated from laboratory batch test results according to comparisons which have been made of the performance of full-scale heat treatment plants with predictions based on laboratory tests. The pH at which sludges are heat treated has an effect on the resulting specific resistance to filtration. Low pH values are much more effective, but corrosion problems are increased. Cooling of heat conditioned sludges prior to atmospheric exposure can reduce odor problems. Increases in the solids content of heat treatment process feed reduces the dewaterability of the conditioned sludge and proportionally increases the liquor's content of dissolved COD, nitrogen, and phosphorus. About 6,000 mg/l of COD is produced for every 1% feed solids present. Increased heat treatment temperature increases soluble nitrogen and decreases the suspended solids of recycle liquor.

A schematic diagram for a typical Porteous process is given in Figure 1. In this process heat is applied to elevate the sludge temperature to 350° to 400°F, and the pressure is raised to 150 to 300 psig. Steam is generally injected into the sludge, and this is followed by a sludge/water/sludge heat exchange system as shown in the diagram. This type of arrangement is known as liquid-coupled heat exchange. It is used because of the difficulties encountered with plugging when sludge was used in the annular pipe of a double-pipe heat exchanger. Air injection is not normally practiced. Basic components of this system include sludge storage, grinding, a preheater, high pressure and temperature reactor, decant thickener, auxiliary liquid treatment, off gas deodorizer, and a steam boiler.

Wet Air Oxidation

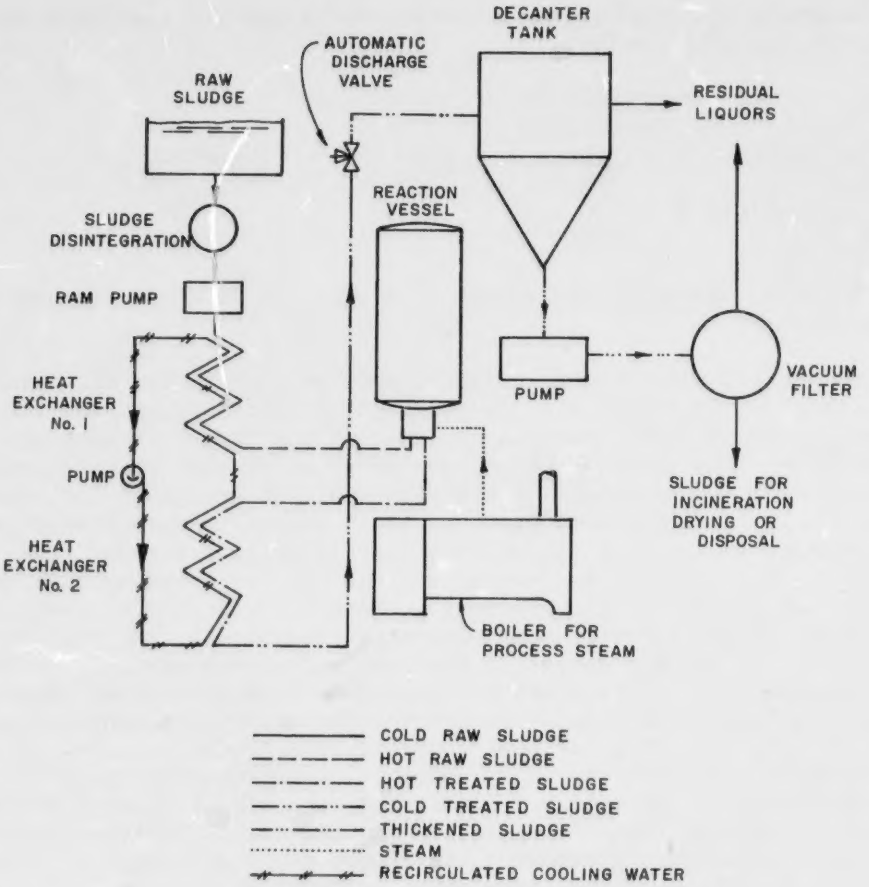
The basis of the wet air oxidation process, which is also referred to as wet incineration or wet combustion, is that any substance which can be burned can be oxidized in the presence of oxygen and liquid water at temperatures of 250° to 1,650°F. The process can operate on difficult to dewater waste liquors and sludges where the solids are but a few percent of the water streams. In general with the proper temperature, pressure, reaction time, and sufficient compressed air or oxygen, any degree of oxidation desired can be accomplished. By operating at lower temperatures and pressures, the same approach may be used for sludge conditioning.

The wet air oxidation process has been commercialized and patented as the Zimpro process. Wet air oxidation does not require preliminary dewatering or drying as required by conventional dry combustion processes. Water can be present up to 99 percent in this process whereas in conventional combustion it must be reduced to much lower levels to make incineration practical.

A significant feature of wet oxidation is the flameless oxidation of the organics at temperatures of 300°F to 400°F for low oxidation and about 700°F for high oxidation when compared to 1,500°F to 2,700°F in conventional combustion processes. Air pollution is minimized because the oxidation takes place in water at low temperatures and no flyash, dust, sulfur dioxide, or nitrogen oxides are formed.

The terms used to categorize the degree of wet oxidation - low oxidation, intermediate oxidation, and high oxidation - refer to the degree of reduction in the COD of the sludge. Higher temperatures are required to effect higher degrees of oxidation, and the higher temperatures, in turn, require the use of correspondingly higher pressures in order to prevent flashing to steam or burning.

Thermal conditioning can be accomplished without oxidation.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HEAT EXCHANGER No. 2
SLUDGE FOR INCINERATION DRYING OR DISPOSAL
BOILER FOR PROCESS STEAM
COLD RAW SLUDGE
HOT RAW SLUDGE
HOT TREATED SLUDGE
COLD TREATED SLUDGE
THICKENED SLUDGE
STEAM
RECIRCULATED COOLING WATER

Figure 1. Porteous process.

Low oxidation, even as low as 5%, oxidizes sulfur and odor-producing organics (which are highly volatile).

The effects of increased holding time in the thermal reactor are to increase the solubilization of COD and color and to degrade fibrous material which would otherwise aid vacuum filtration of the conditioned sludge.

The operating temperature and pressure ranges for the three oxidation categories are given below:

Oxidation	Reduction In Sludge COD, Percent	Temp. F°	Pressure, psi
Low	5	350-400	300-500
Intermediate	40	450	750
High	92-98	675	1,650

With high oxidation the amount of sludge ash is about the same as with incineration.

The general flow diagram of the Zimpro continuous wet air oxidation system is shown in Figure 2. The principal differences between the Zimpro process and the Porteous process are that in the Zimpro process air is added for oxidation, for improvement of heat exchange characteristics, and for reduction of fuel requirements, and that a sludge-to-sludge heat exchanger is employed. In the continuous process, the sludge is passed through a grinder which reduces the size of sludge particles to about 1/4 inch. Sludge and air are then pumped into the system and the mixture is passed through heat exchangers and brought to the initiating reaction temperature. As oxidation takes place in the reactor, the temperature increases. The oxidized products leaving the reactor are cooled in the heat exchangers against the entering cold sludge and air. The gases are separated from the liquid carrying the residual oxidized solids and released through a pressure control valve to a catalytic oxidation unit for odor control. Where economic conditions make it attractive the gases may be expanded in power recovery equipment before being discharged. The oxidized liquid and remaining suspended solids are released through a level control valve and the solids may be separated by settling and drainage in decant tanks, lagoons or sand beds, or by other methods such as vacuum filtration or centrifugation.

For start-up, heat is obtained from an outside source, usually a small steam generator. With high degree oxidations and high-fuel-value sludges, no external heat is needed once the process is started. Whenever the process is not thermally self-sustaining, steam may be injected continuously to maintain the reaction temperature.

Four important parameters control the performance of wet oxidation units: temperature, air supply, pressure, and feed solids concentration. The degree and rate of sludge solids oxidation are significantly influenced by the reactor temperature. Much higher degrees of oxidation and shorter reaction times are possible with increased temperatures. As is the case with conventional incinerators, an external supply of oxygen (air) is

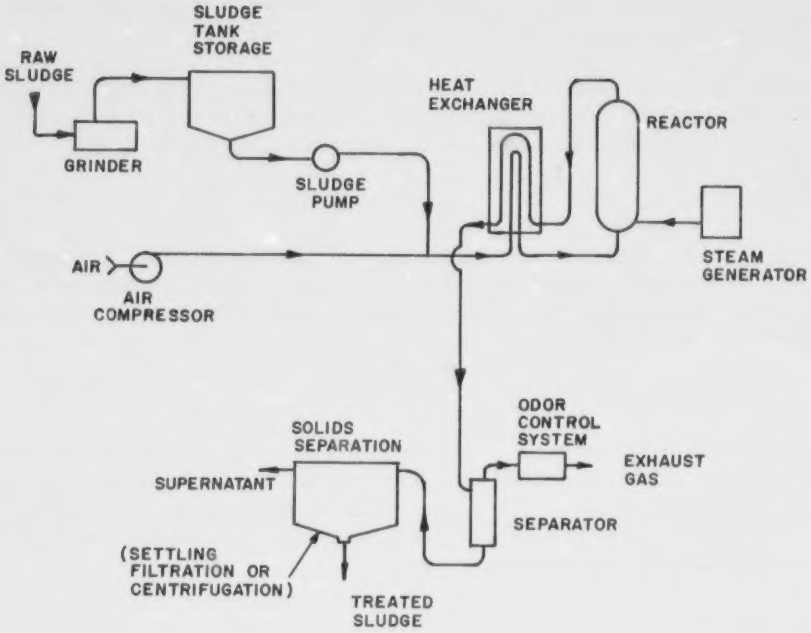

SLUDGE TANK STORAGE
RAW SLUDGE
GRINDER
SLUDGE PUMP
HEAT EXCHANGER
REACTOR
STEAM GENERATOR
AIR
AIR COMPRESSOR
ODOR CONTROL SYSTEM
EXHAUST GAS
SOLIDS SEPARATION
SUPERNATANT
SEPARATOR
(SETTLING FILTRATION OR CENTRIFUGATION)
TREATED SLUDGE

Figure 2. Zimpro wet air oxidation system.

required to attain nearly complete oxidation. The air requirement for the wet oxidation process is determined by the heat value of the sludge being oxidized, and by the degree of oxidation accomplished. Thermal efficiency and process economy are functions of air input, so it is important that the optimum amount be determined. Because the input air becomes saturated with steam from contact with the liquid in the reactor, it is important to control the air also to prevent excessive evaporation of the water. For primary wastewater sludges with a BTU value of 7,800 BTU/lb, an air utilization of 5.75 lb/lb is typical. For an activated sludge with a heat value of 6,540 BTU/lb, an air utilization of 5.14 lb/lb is typical.

The feed solids concentration has a significant effect on operating costs. If the solids concentration is increased from 3 percent to 6 percent, the operating costs may be reduced by as much as 40 percent.

EQUIPMENT

Equipment for thermal conditioning of sludge is manufactured and supplied in the U.S. by BSP (Porteous system), Zimpro (wet oxidation), Barber-Colman (Purtec Wetox system), Zurn (sludge heat treat process), and Nichols (heat treatment process).

Zimpro

In the preceding section, the Zimpro process is described and is illustrated by Figure 2. The majority of operating installations in this country are of Zimpro manufacture. They are for the most part low oxidation plants, but there are also intermediate ozidation, high oxidation, and heat treatment installations of Zimpro equipment.

BSP (Porteous)

The BSP-Porteous system is described in the previous section and is illustrated by Figure 1. There are a number of operating plants in the U.S. utilizing BSP heat treatment equipment.

Barber-Colman

Figure 3 presents a flow sheet for the Barber-Colman Puretec Process. The continuous process begins with the maceration of the incoming sludge which is then pumped through a liquid phase and vapor phase tube-in-tube heat exchanger. Thermal energy from the reactor effluent is recovered and heats the incoming material. The material is then introduced into the Wetox Reactor where it is oxidized at 600 psi at 450° - 465°F temperature. Once the reactor is preheated the process becomes self-sustaining due to the highly efficient destruction of organic waste liberating sufficient energy to maintain temperature.

The organic waste introduced into first compartment is violently agitated to insure rapid reaction, and cascades to subsequent compartments to complete the oxidation process. The incoming material blends with the much

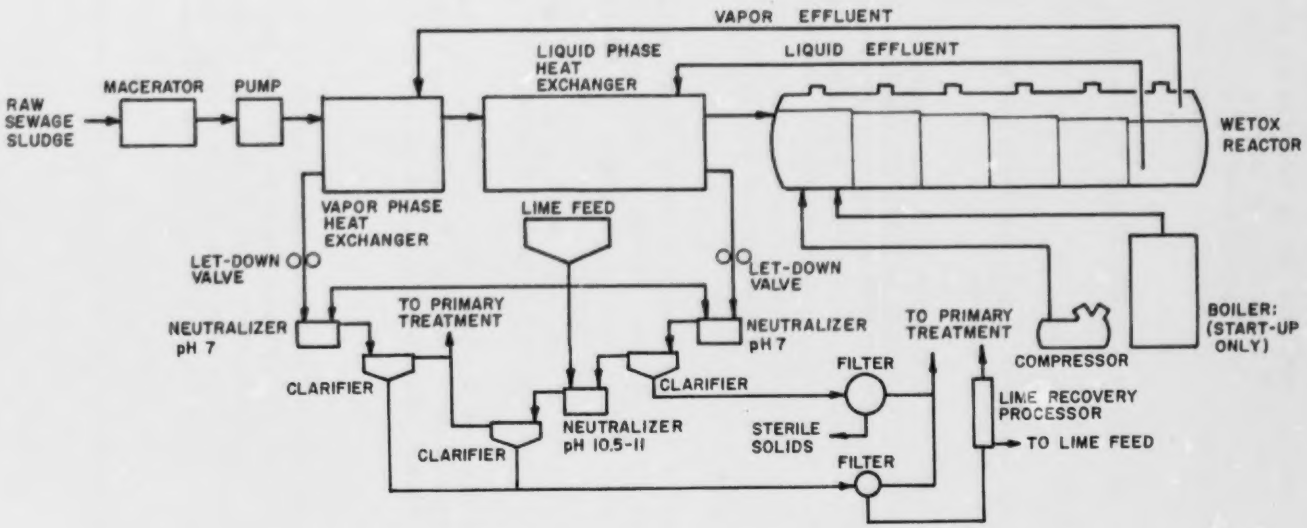

VAPOR EFFLUENT
LIQUID EFFLUENT
RAW SEWAGE SLUDGE
MACERATOR
PUMP
LIQUID PHASE HEAT EXCHANGER
WETOX REACTOR
VAPOR PHASE HEAT EXCHANGER
LIME FEED
LET-DOWN VALVE
LET-DOWN VALVE
TO PRIMARY TREATMENT
NEUTRALIZER pH 7
NEUTRALIZER pH 7
TO PRIMARY TREATMENT
BOILER: (START-UP ONLY)
COMPRESSOR
CLARIFIER
CLARIFIER
FILTER
LIME RECOVERY PROCESSOR
STERILE SOLIDS
NEUTRALIZER pH 10.5-11
CLARIFIER
FILTER
TO LIME FEED

Figure 3. Barber-Colman Puretec Process

larger agitating mass already present in the reactor. In the final compartment, liquid and vapor phases are separated and conducted separately to heat exchangers for thermal energy exchange. After cooling, the vapor phase condensate is let down to atmospheric pressure as is the liquid phase. The flow chart shows the use of lime as a neutralizing agent. This process reduces the acidic effluents to a slightly alkaline solution and precipitates the heavy metals. The lime neutralizing agent is recovered and recycled for re-use.

There are no operating municipal installations in the U.S.

Nichols Heat Treatment Process

This process (previously marketed as the Dorr-Oliver Farrer System) of continuous heat treatment is shown in Figure 4.

The heat treatment process is comprised of a two stage heat exchanger followed by an economizer. The economizer section of the heat exchanger preheats incoming sludge to approximately 300°F by controlling the outgoing treated sludge temperature at 85°F. A booster heat exchanger raises the preheated sludge to the desired final temperature of 360° - 380°F by means of heat from the boiler. The heated sludge then flows through a specially designed reactor, which eliminates short circuiting and insures the desired retention time for full sludge conditioning.

The boiler for the booster heat exchanger can be fired by any of the conventional fuels including digester gas. However, when used in conjunction with incineration, a waste heat boiler can be utilized for additional overall economy in operating costs. A central, automated control panel with full instrumentation minimize operation attention. Following heat treatment the sludge moves to a continuous flow decanting tank for separation.

The Nichols process is used at a plant serving York, Pa. and five installations of the Farrer system were made in the U.S. (San Bernadino, Calif.; Elkhart, Ind.; Port Huron, Mich.; Glouster, N.J.; Norwalk, Conn.).

Zurn

The Zurn Heat Treat Process is shown diagrammatically in Figure 5. The incoming sludge is ground, pumped at 250 psi through a heat exchanger, heated to 380°F, held in a reactor for 45 minutes, cooled in a heat exchanger, held in a thickening tank, and dewatered on a vacuum filter. The vacuum filtrate and the thickener tank overflow are recycled through the wastewater treatment plant.

There is a Zurn system installed at Mentor, Ohio which serves an area in Lake County, Ohio.

Equipment Operating Conditions

In the Pasteurization, thermal conditioning, and wet air oxidation sludge processing systems there are equipment service conditions much like

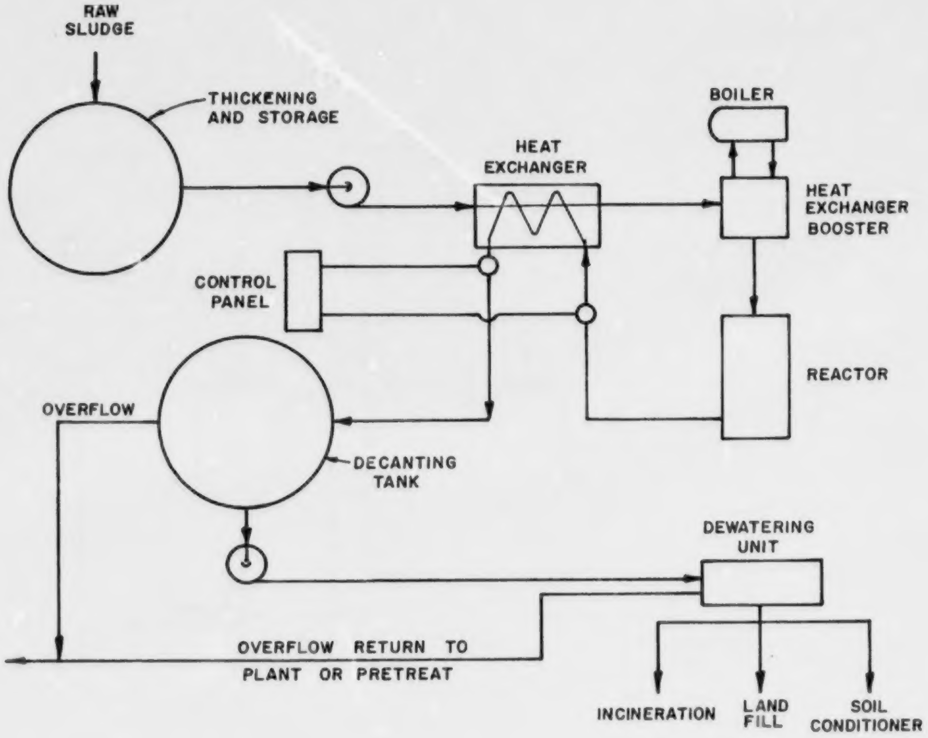

RAW SLUDGE
THICKENING AND STORAGE
BOILER
HEAT EXCHANGER
HEAT EXCHANGER BOOSTER
CONTROL PANEL
REACTOR
OVERFLOW
DECANTING TANK
DEWATERING UNIT
OVERFLOW RETURN TO PLANT OR PRETREAT
INCINERATION
LAND FILL
SOIL CONDITIONER

Figure 4. Nichols heat treatment process.

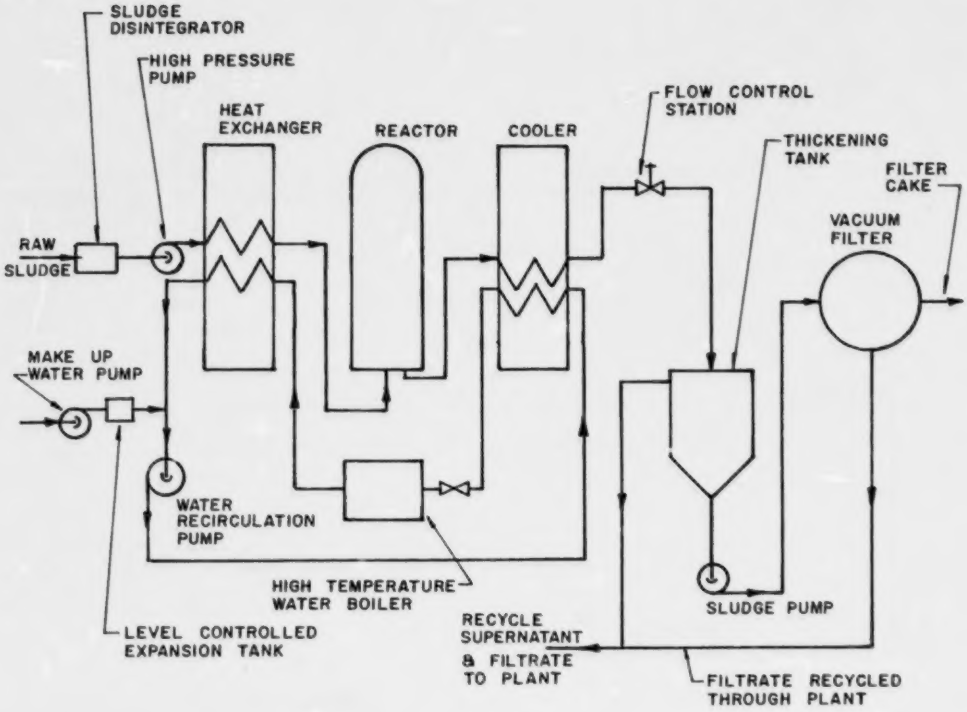

SLUDGE DISINTEGRATOR
HIGH PRESSURE PUMP
HEAT EXCHANGER
REACTOR
COOLER
FLOW CONTROL STATION
THICKENING TANK
FILTER CAKE
VACUUM FILTER
RAW SLUDGE
MAKE UP WATER PUMP
WATER RECIRCULATION PUMP
HIGH TEMPERATURE WATER BOILER
LEVEL CONTROLLED EXPANSION TANK
RECYCLE SUPERNATANT & FILTRATE TO PLANT
SLUDGE PUMP
FILTRATE RECYCLED THROUGH PLANT

Figure 5. Zurn sludge heat treatment process

those in conventional wastewater treatment plants. However, much of the equipment operates under more severe conditions which are not familiar to most treatment plant operators and which may be uncommon to some design engineers and plant supervisors.

Sludge grinders, macerators, disintegraters, and the like operate under the same conditions found in conventional plants. Plastic objects, gravel, grit, and pieces of wood and metal which pass through primary screens and other devices intended to accomplish their removal cause much difficulty in the grinding step. Almost constant operator attention and frequent maintenance is required.

The temperatures and pressures used in thermal treatment are higher than those found elsewhere in wastewater treatment plants and require special consideration in plant design, in the preparation of operator training manuals and courses of instruction, and in plant operation and maintenance.

When air is added under high pressure, the air compressor maintenance requirements differ from those of conventional low pressure equipment. Proper lubricants must be used at regular, manufacturer-prescribed time intervals. Care must be taken to keep carbon or other foreign particles out of the compressor cylinders to avoid scoring of the pistons, cylinder walls, or shafts. Compressor piping must be designed to prevent accidental backup of liquids into the air system and particularly into the compressors. Shaft packing must be properly installed and maintained. Many plant operators fear for their safety when working with or near high pressure and temperature equipment and piping. This fear can only be overcome by furnishing full information to the operators concerning the design and proper operation of the system. High pressure pumps require special attention in operation and maintenance.

Many of the high pressure pumps used in thermal treatment systems are units especially designed for this service and complete data on design and construction features as well as operation and maintenance requirements are essential if the pumps are to be kept in continuous operation without excessive repair costs.

The high temperatures used create special problems of deposition, scaling, and corrosion which must be taken into account in the design of the system, the selection of materials of construction, and in operation and maintenance. The presence of calcium, sulfates, or chlorides in the sludge adds to the difficulties in controlling corrosion and deposition at high temperatures. Calcium sulfate deposits can accumulate rapidly and clog heat exchangers or reactor vessels and piping. Chlorides may be responsible for creating special corrosion or metal stress problems. Corrosion may also result from the presence of organic acids, oxygen, or sulfides. The use of various stainless steels and of titanium is common to resist severe corrosion conditions imposed on wetted metal parts. When air is added to sludge undergoing thermal treatment 316L SS is a minimum material of construction.

Scale and other deposits in heat exchangers or reactors are often removed by washing with 5 percent nitric acid solution for from 4 to 6 hours up to a day. The required frequency for this acid wash may vary from a few weeks to semi-annually depending upon the chemical composition of the sludge being processed. In all cases special treatment or conditioning must be provided for boiler feed water.

Grit, which is present in all sludge in varying amounts, can cause moderate to disastrous results in thermal treatment systems. Grit can accumulate at some low velocity point in the process and subsequently passes through the following portions of the system in a batch or slug that can be particularly damaging to grinders, pumps, or piping. Return bends in piping are especially vulnerable to erosion from grit action. Under the worst conditions return bends may be eroded away completely by grit in only a few weeks. Adequate grit removal from the raw wastewater and from the sludge are absolute necessities for successful operation of thermal treatment systems.

COST IMPACT OF THERMAL TREATMENT ON OTHER PLANT PROCESSES

The use of thermal treatment of sludge affects the cost of other treatment plant processes, decreasing some and increasing others. The calculation of the total cost must include direct capital, operating, and maintenance costs for sludge handling plus or minus the indirect net cost effect of sludge handling on other treatment plant processes.

Reductions

Improvements in the thickening and dewatering characteristics of sludge provided by thermal treatment may reduce the size or capacity of thickening or dewatering equipment required, with accompanying cost savings. If dewatered sludge is to be hauled, then the lower sludge moisture content resulting from thermal treatment will reduce the tonnage to be transported and the cost for disposal. If the dewatered sludge is to be incinerated, then the lower moisture content will reduce incinerator fuel and power consumption. In many cases, the need for chemical additives to aid sludge dewatering is eliminated. Thermal treatment processes also present opportunities for energy recovery from heat values in the waste sludge for various in-plant processes.

Increases

Thermal treatment processes transform many insoluble organic substances in the sludge into soluble materials which appear in the cooking liquor. The liquor overflows the decant tank or thickener or is extracted in the centrifuge, vacuum filter, drying bed, or other dewatering device. With a few possible exceptions, additional costs are involved in processing the BOD load produced in heat treatment.

A second added cost is that for controlling odors produced in heat treatment. Odors emanating from the treated sludge may be released to the atmosphere from the decant tank or thickener, the vacuum pump exhaust, the dewatering device, the strong liquor pretreatment device, or in other places. It is necessary to collect the foul air and to deodorize it before release to the outside air in order to avoid nuisance conditions at the plant and in surrounding areas. Special consideration and provisions for positively controlling odors are essential in every instance.

The cost impact of thermal treatment processes on other plant processes will be discussed in greater detail later in this report, and appropriate costs will be presented.

SECTION VI

THERMAL TREATMENT PROCESS SIDESTREAMS

OFF-GAS

Sources and Character

There are five principal sources of odor in thermal sludge treatment: (1) vapors from treated sludge storage (decant tank or thickener), (2) vacuum filter pump exhaust, (3) vacuum filter hood exhaust, (4) exhausted air from working atmosphere in filter and loading hopper areas, and (5) vapors from strong liquor pre-treatment devices. The air from sources (1), (2), and (5) are high in hydrocarbon content, while that from sources (3) and (4) are low in hydrocarbon content.

The odorous gases produced are simple, low molecular weight, volatile organic substances, consisting of aldehydes, ketones, various sulphurous compounds, and organic acids. Each class of compounds that is present in the vapors contains members of its homologous series beginning with the lowest molecular weight and continuing on to perhaps the C_7 or C_8 member. For example, the aldehydes that are present begin with formaldehyde and include acetaldehyde, propionaldehyde, etc., continuing on to caproic aldehyde. In the laboratory the total organic content of the exhausted process vapors can be measured by means of the flame ionization detector. The odor level of each uncontrolled odor source associated with thermal sludge conditioning units is dependent to a high degree on the total hydrocarbon content.

Odor measurement and determination of odor threshold levels are best done by a test panel using the human nose rather than by monitoring instruments. If the odor threshold, as determined by the human test panel, is reached when one volume of the odorous sample is diluted to 100 volumes with odor free air, the odor concentration in the odorous sample is reported to be 100 odor units per cubic foot.

Collection

A foul air collection system is an essential part of any thermal treatment system. Sludge decant tanks, thickeners, strong liquor pretreatment tanks, loading hoppers, and vacuum filters should be covered or hooded so that the odorous gases can be collected and subjected to methods for hydrocarbon reduction before release to the atmosphere. The vacuum filter pump exhaust pipe should also be discharged through an odor control device.

Odor Control Methods

Odor control methods include: combustion, adsorption, scrubbing, masking, dilution, and surface evaporation control. The concentrated off-gases are best controlled by use of incineration, adsorption, scrubbing, or combinations thereof. The dilute off-gases may be treated by adsorption or scrubbing, or, in some cases, by masking and dilution.

Water Scrubbing Plus Incineration--

For high hydrocarbon air streams, the highest degree of odor control can be obtained by water scrubbing followed by incineration. The scrubbing portion of this system consists of a packed bed unit which uses plant effluent water at rates of 20 to 30 gpm per 1,000 cfm.

The incineration portion of this system can be either direct flame incineration at 1500°F or catalytic incineration at 800°F. The oxidation catalysts that are commonly used in catalytic incineration are supported platinum or palladium materials. Odor levels of the exhausted air from this system can be reduced to less than 100 O.U./SCF if the incinerator is oil fired, and less than 25 O.U./SCF if gas fired.

The low hydrocarbon odor sources are high volume streams, and the operational cost of afterburning is prohibitive.

Water Scrubbing Plus Adsorption--

In scrubbing methods, the odorous substances are removed by solubilization, condensation, or chemical reaction with the scrubbing medium. Scrubbing media that are commonly used for odor control are potassium permanganate, sodium hydroxide, or sodium hypochlorite. Two to four pounds of potassium permanganate are required per pound of hydrocarbon removed.

In the adsorption method, the odor substances are removed from the odorous gas stream by adsorption on activated carbon or silica gel. When the adsorption method is applied to odor control of processes, the adsorptive medium, activated carbon or silica gel, must be capable of regeneration usually by steaming.

High hydrocarbon sources can be treated in an odor control system composed of a water scrubber followed by an activated carbon adsorption unit. The water scrubber is the same as that described above. The carbon adsorption unit is a multiple bed adsorber that is sized to minimize the required number of steam regenerations. Normally, the carbon bed would be sized so that only one steam regeneration per day would be required. Treating a 1,000 CFM gas stream would require a dual bed carbon system containing 1,800 pounds of carbon per bed. This sizing would permit an adsorption cycle of 24 hours. After a 24 hour adsorption time, the second carbon bed would be placed in the adsorption cycle and the spent bed would be steam regenerated. The regeneration cycle requires low pressure steam at a maximum of 50 psig for a period of one hour. The steam and desorbed organic compounds from the bed are condensed and collected. The aqueous condensate is returned to the head of the treatment plant and the liquid organic phase is incinerated. This water scrubbing-carbon adsorption odor control system can produce an exhaust with an odor level ranging from 50 to 300 O.U./SCF.

A word of caution is in order when odors due to hydrogen sulfide or mercaptans are to be adsorbed on activated carbon. These sulfur compounds may be air oxidized to elemental sulfur which is not removable by steam stripping and which may plug the carbon bed.

The applicability of carbon adsorption to low hydrocarbon odor sources must be decided on a case-by-case basis.

Multiple Scrubbers--

A third option for treating high hydrocarbon sources is a multiple scrubber system. The multiple scrubber system would contain at least two and preferably three scrubbing stages. In all cases, the first scrubbing stage of the multiple scrubber system should be water scrubbing using plant effluent water at a rate of about 27 gpm per 1,000 CFM. The second and third stages should be chemical scrubbing stages using a combination of scrubbing media selected from 5 percent sodium hydroxide, 3 percent sodium hypochlorite, and 3 percent potassium permanganate. The potassium permanganate solution affects the highest degree of hydrocarbon reduction and, hence, the highest odor reduction. One of the most effective multiple scrubber systems would consist of three stages and would utilize plant effluent water in the first stage, 5 percent sodium hydroxide in the second stage, and 3 percent potassium permanganate in the final stage. This system would affect a hydrocarbon reduction of 80 to 90 percent and would produce an exhaust with an odor level of 100 to 250 O.U./SCF.

In one plant a nitrifying trickling filter has been used as a biological scrubber with the primary effluent serving as scrubber water.

As with carbon adsorption, the suitability of scrubbing for low hydrocarbon sources must be decided on an individual basis. The greatest consideration in choosing between carbon adsorption and scrubbing is usually the space requirement of the selected system. The space requirement for the carbon adsorption system is quite large, whereas, the chemical scrubbing system can be accomodated in lesser space.

Additives and Dilution--

When additives are used, odor control is achieved by masking or counteracting odorous substances. Odor counteraction implies that the intensity of an odor is reduced as detected by the human olfactory sense. In contrast, odor masking implies that the odor is obscured. Actually, both terms, masking and counteracting, are used interchangeably. Masking agents include orange fragrance and Malabate (proprietary chemicals).

In the dilution method, the intensity of an odor is reduced by diluting the odorous stream with odor-free air. This dilution can be achieved by actual addition of air to the odorous stream or by affecting dilution subsequent to exhausting by utilizing tall stacks or by increasing the exhaust gas velocity.

The chemical reaction of the hydrocarbon compounds from the thermal sludge conditioning odor sources with ozone is rather slow and often times produces peroxides and hydroperoxides which are more offensive than the original hydrocarbon. Hence, direct ozonation is not an effective odor control method. However, if the hydrocarbon odor sources are diluted with other non-hydrocarbon odor sources which react with ozone, then the composite gases might be deodorized by the ozonation method.

The ozonation method for controlling odors from thermal sludge treatment units should be considered only when total odor control is to be provided for the entire treatment plant. An example of this type of odor control system is the operating system at Midland, Michigan. In this system the gases from the sludge conditioning building, which include both high and low hydrocarbon sources, are combined with gases from the covered trickling filters, from a flow equalizing tank, from the primary building, and from the grit building. The gases from the sludge conditioning building comprise one-fourth of the total 28,000 CFM air flow through the ozone contact chamber. The composite gases in the ozone contact chamber are normally treated with one to two ppm ozone and a detention time of 30 seconds. The total capacity of the ozone generators is 34 pounds per day of ozone which could produce a maximum ozone concentration of approximately seven ppm.

The use of additives, whether masking agents or odor counteractants, cannot be considered as an ultimate solution of any odor problem. However, this odor control method might be employed on a short term basis until a more absolute method could be implemented.

The use of the dilution method for odor control is often suspect. All of the varieties of this method are dependent on subsequent atmospheric dispersion which is prone to failure during certain weather conditions. Dilution methods are usually employed in conjunction with one or more of the above hydrocarbon reducing methods and, hence, aid in the overall effectiveness of each applied odor control method.

Additives and dilution may be applied in series for treatment of low hydrocarbon sources.

Surface Evaporation Control--

Odors escaping from the surface of open tanks have been controlled by covering the tank surface with small floating plastic balls which reduce evaporation and thereby reduce odors.

THERMAL TREATMENT LIQUORS

Sources and Composition

The strong liquors containing the materials solubilized during heat treatment of sludge may be separated from the solids (1) during storage in decant tank, thickener, or lagoon, and (2) in the dewatering step using a vacuum filter, centrifuge, sand drying bed, or other method. The quantity of liquor is about 0.5 percent of plant inflow.

The concentrations of COD, nitrogen, and phosphorus in the liquor are proportional to the feed solids concentration. For example, about 6,000 mg/l of COD is solubilized for every 1 percent solids in the heat treatment process feed. Increases in the temperature used in thermal treatment increase the amount of nitrogen solubilized during the process, and as much as 70 percent of the total nitrogen in sludge may go into solution at high temperatures. On the other hand, suspended solids may decrease at increased temperatures. Effects of increased holding time in thermal reactors are to increase the solubilization of COD and color.

Some of the substances present in thermal treatment liquor and the general ranges of concentration are tabulated below:

Substances in Strong Liquor	Concentration Range, mg/l (except as shown)
SS	100 - 20,000
COD	10,000 - 30,000
BOD	5,000 - 15,000
NH_3-N	400 - 1,700
Phosphorus	150 - 200
Color	1,000 - 6,000 units

The exact composition of thermal treatment liquor varies widely depending upon temperature, reaction time, feed solids, air addition, sludge composition, and other factors which are considered in more detail in the review of data gathered from operating thermal treatment installations later in this report.

A limited amount of available information on the fate of nutrients during the thermal treatment shows that 60-90 percent of the phosphorus present in the feed typically remains in treated sludge while 60 to 80 percent of the ammonia feed remains with the liquor.

Direct Recycle

Thermal treatment liquor often is recycled through the main treatment plant, being introduced to the raw sewage or primary effluent. This places an additional load upon the system principally in the form of oxygen demand, suspended solids, and color. In most cases the color of the final effluent is increased. This may also be true of the BOD and SS in the effluent if the main plant is fully loaded or if operation of the main plant is not changed (i.e., increase air supply) to handle the increased loadings. If effluent BOD and SS quality is maintained by adjustments in treatment, then the total cost of treatment is increased. The effects of recycle can be mitigated to some extent by storing the thermal treatment liquor and returning to the treatment plant at a uniform rate or during off-peak hours. The BOD and SS in thermal treatment liquor may amount to 10 to 50 percent of the total plant load, as will be seen in later sections of this report.

Separate Treatment and Disposal

Another method for handling liquors processes the sidestream separately and with no return of any liquor to the main treatment plant. Sometimes digester supernatant and waste activated sludge are combined with the thermal treatment liquor for separate processing; one example of this is the installation at Indio, California where aerated lagoons with long retention provide excellent service. Lagoon effluent is blended with plant effluent for discharge.

Separate Treatment Prior to Recycle

In order to reduce the load on the main treatment plant and maintain final effluent quality, thermal conditioning liquor is often subjected to separate treatment prior to its reintroduction to the main plant flow stream by addition to raw sewage or primary effluent. Again, digester supernatant may be combined with the liquor for pretreatment.

The Thames Conservancy District of England requires pre-treatment of liquor and recommends a conceptual design including a roughing filter, 49 hours aeration, and 2 to 3 stages of downflow contact with granular activated carbon (Figure 6). This pre-treatment scheme is designed to reduce the COD of the liquor from 20,000 to 100 mg/l before recycle to the treatment works.

Plain aeration, extended aeration, and activated sludge treatment have also been used for pretreatment of thermal treatment liquors with and without dilution with sewage. BOD reductions by conventional activated sludge pre-treatment of liquor have been reported as high as 90 percent. In some cases as much as 30 percent of the liquor COD has proven to be nonbiodegradable. It may be necessary to collect and deodorize aeration basin off-gases before release.

Thermophilic aerobic digestion is another process that has potential for treating high-strength liquors. Because of the high endogenous decay value reported for liquors, this process should be very efficient and should be studied.

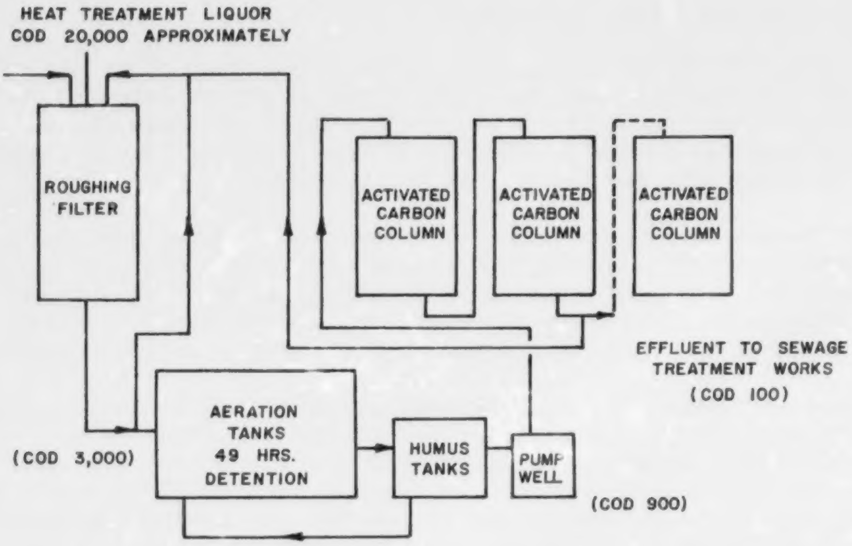
Another proposed method calls for pre-treatment of liquor by anaerobic filters for 75 to 90 percent BOD reduction followed by chlorination to oxidize sulfur compounds. The effluent would go the secondary treatment system. Off-gases from the anaerobic filter would be burned. A potential advantage of this type of process is that the amount of biological solids produced is much less than in aerobic processes.

Because of the high nitrogen content, land disposal of heat treatment liquors has also been proposed.

Effects of Recycle on Plant Loadings and Process

There are a number of variables which influence decisions regarding the handling and final disposal of thermal treatment liquor.

As already mentioned, thermal treatment liquor varies widely to composition and strength depending upon raw sludge character, feed solids concentration, treatment temperature, contact time, amount of air added, and other


HEAT TREATMENT LIQUOR
COD 20,000 APPROXIMATELY
ROUGHING FILTER
ACTIVATED CARBON COLUMN
ACTIVATED CARBON COLUMN
ACTIVATED CARBON COLUMN
EFFLUENT TO SEWAGE TREATMENT WORKS
(COD 100)
AERATION TANKS
49 HRS. DETENTION
HUMUS TANKS
PUMP WELL
(COD 3,000)
(COD 900)

After Fig. 6-6, EPA Technology Transfer "Process Manual for Sludge Treatment and Disposal" (October 1974)

Figure 6. Schematic diagram of plant for processing heat treatment liquor.

factors. Laboratory or pilot plant tests can yield useful information along these lines.

Untreated liquor may be recycled directly to raw wastewater or biological process influent.

The liquor may be processed entirely independently from the main wastewater flow. The thermal treatment liquor may be combined with digester supernatant or waste activated sludge and the mixture processed separately. In these cases, the effluent from the treated sidestream may be added to the raw wastewater, the primary effluent, or the final effluent, or it may be disposed of separately from the main plant flow.

The discharge requirements will influence many of the decisions to be made regarding handling of thermal treatment liquor treatment and disposal.

Liquors from thermal treatment may produce increases in the main plant effluent BOD, COD, SS, NH_3, color, or phosphorus content which are sufficient to require separate pre-treatment or improved in-plant treatment to meet discharge requirements. The cost impact of the pre-treatment or expanded plant facilities to meet the standards are a principal concern of this study. Usually the primary considerations in direct recycle are the need for handling of added BOD and SS loads. The fact that these added loads can make up anywhere from 10 to 50 percent of the total load on the plant is significant from a cost as well as a plant performance standpoint. The costs of separate processing for thermal treatment liquors or the incremental costs associated with recycle represent added costs for wastewater treatment. Means for estimating these costs will be developed later in this report along with estimating procedures for direct costs involved in thermal treatment of sludge.

SECTION VII

CASE HISTORIES

GENERAL

Plant visits by CWC engineers have been a major source of data for this study. At each of these visits an extensive interview was conducted with management or chief operating personnel. In most cases the plant was also inspected. A detailed report form was completed for each interview. These forms were submitted in the monthly reports and will not be repeated in the final report. Table 1 lists the 36 treatment plants contacted.

A total of 28 plants were visited, with an additional seven plants supplying data by correspondence and one plant supplying a limited amount of data by telephone. Of the plants visited, 21 were manufactured by Zimpro and 7 by BSP. One high oxidation and three intermediate oxidation Zimpro plants were visited.

A brief description of special features in the installation and operations of the plants visited is provided in this chapter. These case histories are grouped according to the type of heat treatment they employ. Plants where data were obtained by correspondence or telephone are not described. Table 2 is a tabulation of installation and operating conditions for the plants visited. An experience summary of the plant visits follows the case histories.*

PLANTS VISITED

North Olmstead, Ohio

The City of North Olmstead has installed a Zimpro low oxidation sludge conditioning process at its activated sludge plant. The plant includes phosphorus removal, with sodium aluminate, and tertiary micro-strainers. All sludge from the plant is gravity-thickened, then heat treated, vacuum-filtered, and given to local residents as a soil conditioner. The heat treatment is normally operated 24 hours per day, seven days per week.

The return liquid streams from the oxidized sludge tank and vacuum filters are given separate, extended aeration treatment in an unused aeration tank. Three days aeration reduces the BOD to about 40 mg/l. This effluent is sent to the gravity thickener along with the sludges from primary sedimentation, waste activated sludge, and the micro-strainer. The underflow from the thickener is sent to the heat treatment and the overflow

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* See Appendix C for more current summary of case histories.

TABLE 1

THERMAL TREATMENT PLANTS CONTACTED

Plants Visited	Month Visited	Manufacturer	Type
Colorado Springs, Colo.	June	BSP	thermal
Portland, Oregon	Aug.	BSP	thermal
Gresham, Oregon	Aug.	BSP	thermal
Vancouver, Washington	Aug.	BSP	thermal
Muskogee, Oklahoma	Sept.	BSP	thermal
Denton, Texas	Sept.	Zimpro	low
Indio, California	Oct.	Zimpro	low
Clark County, Nevada	Oct.	Zimpro	low
So. Milwaukee, Wisconsin	Oct.	Zimpro	interm, batch
Rothschild, Wisconsin	Oct.	Zimpro	low
Merrill, Wisconsin	Oct.	Zimpro	thermal
Wausau, Wisconsin	Oct.	Zimpro	low
Terre Haute, Indiana	Oct.	Zimpro	low
North Olmsted, Ohio	Dec.	Zimpro	low
Bedford Heights, Ohio	Dec.	Zimpro	low
Akron, Ohio	Dec.	Zimpro	high
Canton, Ohio	Dec.	Zimpro	low
Lucas County, Ohio	Dec.	Zimpro	low
Columbus, Ohio (Jackson Pike)	Dec.	Zimpro	low
Cambridge, Md.	Jan.	Zimpro	low
Lancaster, Pa. (South Plant)	Jan.	Zimpro	low
Millville, New Jersey	Jan.	Zimpro	low
Levittown, Pa.	Jan.	Zimpro	low
Westchester Co., N.Y. (Blind Brook)	Jan.	Zimpro	interm.
Rockland Co., N.Y.	Jan.	Zimpro	interm.
Groton, Conn.	Jan.	BSP	thermal
Gloversville-Johnstown, N.Y.	Jan.	Zimpro	low
Cincinnati, Ohio (Muddy Creek)	Jan.	BSP	thermal
Data by Correspondence			
Speedway, Indiana	---	Zimpro	low
Midland, Michigan	---	Zimpro	low
Kalamazoo, Michigan	---	Zimpro	low
Defiance, Ohio	---	Zimpro	low
Mayfield, Kentucky	---	Zimpro	low
Amsterdam, N. Y.	---	Zimpro	low
Grand Haven, Michigan	---	Zimpro	low
Checked by Telephone			
Chattanooga, Tennessee	---	Zimpro	interm.

TABLE 2

INSTALLATION AND OPERATING DATA FOR PLANTS VISITED

Plant and Type	Size[1] gpm	Equipment Manufacturer	Operating Temperature °F	Operating Pressure psig	Type of Sludge	Initial Operation Date	Liquid Plant Design Flow mgd	Present[2] Average Flow mgd
Low Oxidation								
Denton, Texas	33	Zimpro	390	350	P+AS	1970	6	7.3(75)
Indio, California	30	Zimpro	390	350	P	1969	5	1.8(75)
Clark Co., Nevada	117	Zimpro	350	400	P+TF	1974	32	27.0(75)
Rothschild, Wisconsin	6.7	Zimpro	360	300	P+AS	1969	1.5	0.7(74)
Wausau, Wisconsin	38	Zimpro	375	350	P+AS	1969	11.2	6.5(75)
Terre Haute, Indiana	50	Zimpro	-	-	DP+AS	1972	-	11.3(74)
North Olmsted, Ohio	34	Zimpro	270	300	P+AS	1973	9	6.0(75)
Bedford Heights, Ohio	26	Zimpro	390	300	P+AS	1970	3.6	2.3(76)
Canton, Ohio	2x75	Zimpro	370	350	DP+AS	1973	30	21.0(75)
Lucas Co., Ohio	33	Zimpro	365	300	AS	1973	5	2.2(75)
Columbus, Ohio (Jackson Pike)	200	Zimpro	380	370	P+AS	1972	80	60.0(75)
Cambridge, Md.	65	Zimpro	350	300	P+AS	1975	8.1	4.2(76)
Lancaster, Pa. (South Plant)	40	Zimpro	350	350	P+AS	1973	12	9.0(76)
Millville, N.J.	36	Zimpro	330	325	P+AS	1970	5	2.5(76)
Levittown, Pa.	35	Zimpro	360	340	P+AS	1967	10	9.0(76)
Gloversville-Johnstown, New York	100	Zimpro	350	300	P+AS	1972	13.5	10.6(76)
Thermal Conditioning								
Colorado Springs, Colo.	83	BSP	400	210	P+AS	1974	30	16.0(74)
	75	BSP	380	200	P+TF	1968	14	-
Portland, Oregon	2x75	BSP	400	210	P+AS	1975	100	77.8(75)
Gresham, Oregon	33	BSP	375	275	P+AS	1973	6	3.8(75)
Vancouver, Wash.	66	BSP	365	170	P+AS	1974	12	7.0(75)
Muskogee, Oklahoma	50	BSP	400	250	P+TF	1972	6.5	6.5(75)
Merrill, Wisconsin	25	Zimpro	400	300	P+AS	1974	2.1	1.2(74)
Groton, Conn.	32	BSP	375	250	P+AS	1974	5.5	-
Cincinnati (Muddy Creek) Ohio	67	BSP	350	275	P+AS	1973	15	8.0(76)
Intermediate Oxidation								
So. Milwaukee, Wisc.	Batch 2 t/d	Zimpro	500	400	DP+AS	1961	6	3.0(75)
Westchester Co., N.Y. (Blind Brook)	83	Zimpro	450	750	P	-	5	2.5(76)
Rockland Co., N.Y.	50	Zimpro	400	800	P+AS	1969	10	15.0(76)
High Oxidation								
Akron, Ohio	2x75	Zimpro	550	1650	AS	1971	87.5	90.0(74)

LEGEND

D = digested
P = primary sludge
TF = trickling filter humus
AS = waste activated sludge

(1) In some cases size in gpm has been estimated from reported capacity in tons per day.
(2) Figure in parenthesis is the year for which flow was reported.

from the thickener is sent to the head of the treatment plant. This separate recycle treatment works well and it is planned to build a special treatment tank for this purpose when the aeration tank needs to be returned to sewage treatment.

Odors from the heat treatment off-gas have been a severe problem at North Olmstead. The plant is located on low ground near the river bank with homes on the surrounding higher ground. Odors are now satisfactorily controlled by use of a city-designed and built high temperature gas after-burner which receives all off-gas from the oxidized sludge tank and the vacuum filters. Ozone treatment was tried, but it was not adequate. The original Zimpro supplied catalyst burner was retained for treatment of the gas-liquid separator off-gas with the addition of an air scrubber using effluent water. The oxidized sludge tank and vacuum filters are fully enclosed.

Bedford Heights, Ohio

The City of Bedford Heights has a Zimpro low oxidation heat conditioning plant at its activated sludge plant. Forty percent of the Bedford Heights flow is industrial with a high amount of pickling liquor, which accounts for a high phosphorus removal without special chemical treatment. Activated sludge is wasted to primary sedimentation and the combined sludge is processed by the Zimpro unit. The heat treatment plant has had extensive mechanical problems which have resulted in a 50 percent down-time from 1970 to summer 1975, when the heat treatment was taken out of service. These mechanical problems have centered on the grinders, boiler, and heat exchanger. The oxidized sludge tank was converted from an old digester and not equipped with decanting facilities, so an abandoned and undersized sludge thickener was adapted for limited decanting. The plant was operated 24 hours per day, seven days per week.

The recycle streams were returned to the head end of the plant. They did not cause any treatment problems, since the plant has extra, unused air capacity, however, there was concern about effluent color during low flows. The recycle streams caused odors from the liquid treatment tanks. Because of the odors, pre-aeration of the recycle streams in old septic tanks was tried. It showed a good degree of treatment. Hydrogen peroxide was also added to the recycle stream.

Off-gas from the oxidized sludge tank caused odor problems. The original catalyst burner was not effective in odor treatment, nor were acid and caustic scrubbers or ozone. If the plant is put back in service and natural gas can be obtained, it is planned to purchase a high temperature afterburner for off-gas treatment.

Akron, Ohio

The City of Akron has two separate processes for the treatment of sludge from its activated sludge plant. The primary sludge is vacuum filtered raw and incinerated. The waste activated sludge is thickened and treated in a high oxidation Zimpro plant. The volatile solids reduction in the high oxidation heat treatment is 86 percent and the COD reduction is 83 percent.

The oxidized sludge is sent to two decant tanks which are converted from trickling filters. The decant liquid is returned to the plant. There is no problem in treating this recycle liquor because the high oxidation in the reactor has reduced the BOD. When the decant tank is filled with sludge which takes about one year, it is slowly drained. The resulting solids have about 50 percent moisture and are removed with mechanical equipment and hauled to a landfill. The decant tanks are uncovered and there is no odor problem. The plant is equipped with a scrubber using effluent water and a gas-fired incinerator to treat process off-gas.

The City has had a satisfactory operating record with the equipment. Down periods are confined to routine maintenance or waiting for replacement parts. Because they have dual units, they generally have been able to keep one unit operating by shifting parts between units. Once the reactor is up to temperature the reaction is thermally self-sustaining. A steam turbine was installed for waste heat power recovery, but the system has not been used much. The mechanical design has been modified and they hope to use it regularly in the future.

An analysis of operating costs by the City for six months in 1974 showed the cost of primary sludge disposal by vacuum filtration and incineration to be $86 per dry ton. The cost of waste activated sludge disposal for the same period by high oxidation heat treatment and settling was $78 per dry ton.

Canton, Ohio

The City of Canton has installed a Zimpro low oxidation heat conditioning process for treating the sludge from its activated sludge plant. Plant operations are presently in a period of transition due to new plant construction. The new sludge handling facilities have been completed, but the new activated sludge plant is still under construction. At present activated sludge is wasted to the primary tanks. About half of the combined sludge from the primary tanks is anaerobically digested before heat conditioning and the other half is heat conditioned raw. The conditioned sludge is vacuum filtered and trucked to a landfill. When the liquid plant expansion is completed, anaerobic digestion well be discontinued and the dewatered sludge will be incinerated. The raw sewage is about one-third industrial with a high metal content. After frequent initial mechanical problems, heat treatment is now a reliable and satisfactory process. Canton has a two reactor system with an extra high pressure pump, air compressor and boiler. The major operating problem is in solids dewatering. The anaerobically digested sludge does not filter will after heat treatment. The solution has been to use a mixture of one-half digested and one-half undigested sludge. Poor filtration resulted in a build up of fine solids in the aeration tanks and plant effluent. No chemicals are used in filtration. The recycle liquors are returned to the head of the aeration tanks. There is no problem in treating these recycle liquors, although extra air is required and there is a noticeable color to the effluent. Odors are not a significant problem at the plant. Off-gas from the decant tank are treated in a gas incinerator supplied by Zimpro. The air-water separator after the reactor is bypassed because it accumulated grit.

Lucas County, Ohio

Lucas County, Southwest of Toledo on the Maumee River, has a Zimpro low oxidation heat conditioning process for its contact stabilization wastewater treatment plant. There is no primary sedimentation. There is phosphorus removal by application of liquid alum to the aeration tank outlet. A self-cleaning rotary screen has been installed after the secondary sedimentation tanks and before the gravity sludge thickener. Use of the screen has allowed by-passing the sludge grinders. The sewage is domestic in origin, with no significant industrial discharges. The heat treatment operates well. The only significant down-time has been due to mechanical problems during start-up. The heat treatment is operated 7 hours per day, five days per week. The local water supply from Lake Erie is soft, and frequent acid washing has not been necessary. The treated and dewatered sludge is stockpiled on the plant grounds. The supernatant and filtrate are returned to the head of the contact tank. There are no problems in treating the recycled BOD load since the plant flow is below rated capacity. There are no odor problems and normally no odor control equipment is operated. The plant is in a rural location.

Columbus, Ohio (Jackson Pike Sewage Treatment Plant)

The Jackson Pike Sewage Treatment Plant of the City of Columbus uses a low oxidation Zimpro sludge process to condition the sludge from its activated sludge plant. The single 200 gpm unit operates 24 hours per day, seven days per week to process a major portion of the sludge. The remaining sludge is anaerobically digested, chemically conditioned and vacuum filtered, with a small portion of the raw sludge vacuum filtered directly. A second 200 gpm unit was bid in January, 1976 and eventually will replace the anaerobic digestion. The present vacuum filters for dewatering the heat treated sludge will be replaced with centrifuges. The sludge is disposed of by landfill or incineration. It is expected that incineration will be thermally self-sustaining when the second Zimpro unit is operating. Operation of the thermal process has been irregular, with 35 percent down-time. Grinder failures and high pressure pump problems have been frequent. The local water supply has 8 grains of hardness, which is sufficient to cause scaling problems in the heat exchanger. The acid washing has not been very effective. Supernatant and filtrate are returned to the head of the aeration tank. Odor from the heat treatment units is noticeable on the plant grounds. A Zimpro supplied fume incinerator is used on the decant tank off-gas. There is no odor control on the filter room. It is planned to install ozone odor control equipment in the new installation.

The City of Columbus is also installing three 200 gpm Zimpro units in its Southerly treatment plant. These units are to be computer controlled to improve efficiency and balance flows but it is not expected that the computer will reduce the manpower required to operate the units.

Cambridge, Maryland

The City of Cambridge has recently begun operation of its Zimpro low oxidation heat conditioning process. The plant conditions both primary and waste activated sludge. There is considerable sea water infiltration into the older sewers laid along the shores of Chesapeake Bay. Initial operation of the thermal process was delayed about two years because the heat exchanger tubes were changed from stainless steel to titanium due to concern about corrosion from infiltrated sea water. Operation has been intermittent the first half year due to startup problems. Cambridge sewage has large seasonal industrial loads from processing fish and farm products which have a high grease content. The operators have been observing a rising grease content in the sludge and are concerned that this may be related to the conditioning plant operations. The supernatant and filtrate from the process are returned to the plant headworks. They do not cause any operating problems since there is adequate excess aeration capacity available. The heat treatment is operated one eight-hour shift per day from three to five days per week depending upon the amount of industrial sludge. The treated and dewatered sludge is hauled 16 miles to a landfill for disposal.

Local residents are vigorously protesting odors from the heat treatment processes. There are homes directly across the street from the treatment plant. Off-gases from the decant tank are treated in a gas incinerator supplied by Zimpro. The vacuum filter is in a separate room of the sludge building and without odor control equipment. Plant personnel hope to control odors from the recycle liquor by constructing covers over the hopper areas of the primary tanks and discharging the supernatant and filtrate at a depth of six feet into the primary tank, instead of the present discharge to the headworks.

Lancaster, Pennsylvania

The City of Lancaster operates a Zimpro low oxidation heat treatment process at its Stanley D. Nissley Water Pollution Control Plant (South Plant) to condition primary and waste contact stabilization sludge. The plant operates satisfactorily 24 hours per day, five days per week. The dewatered sludge is given to farmers to put on agricultural land. The recycled streams are returned to the head end of the plant. There are relatively few odor complaints and these occur only during unusually still air. Therefore, the high temperature odor incinerator for the decant tank off-gases is not normally operated.

Millville, New Jersey

The City of Millville has operated a Zimpro low oxidation sludge conditioning process for six years. Operation has been continuous with only minor problems during the initial startup. During the inspection the plant was down for its first major overhaul. The plant treats primary and waste activated sludge from a contact stabilization plant. Dewatered sludge is stockpiled at the plant and given away. No adjustments are made in the operations for the recycle streams and there are no problems in treating the recycle. Supernatant is displaced from the decant tank only when the heat treatment is running eight hours per day, five days per week. It is returned to the head of the plant with the filtrate. However, the entire plant is operated even though the present flow is only one-half of the design capacity. There are some homes in the general plant areas, but only a few of these complain about odor during the summer when the air is still. The plant is equipped with a catalytic burner for the decant tank off-gas, but this burner is never used. There is no other odor control equipment at the plant.

Levittown, Pennsylvania

The Levittown Plant of the Lower Bucks County Joint Municipal Authority has employed a Zimpro low oxidation process for its activated sludge plant since March, 1967. This unit operates 24 hours per day, seven days per week, with a shutdown every 21 days for acid washing. The unit operates reliably with one operator-mechanic on one shift and with operators on other shifts checking the unit and cleaning the grinders. The supernatant and filtrate recycle streams are returned to the head end of the plant. They do not cause any operating problem, even though the plant flow is near its rated capacity. Sludge after dewatering is hauled to a landfill. The off-gas from the heat treatment process is bubbled into a tank containing plant effluent continuously pumped from the chlorine contact basin. The overflow from the tank returns to primary sedimentation and sludge is removed from the tank once per year. There are no odor complaints, even from a popular restaurant about one hundred yards from the plant.

Westchester County, New York

The Blind Brook Water Pollution Control Plant of Westchester County is located in Rye, New York. This intermediate oxidation Zimpro plant conditions the primary sludge from a primary sedimentation plant. An 85 percent reduction in volatile solids is obtained from the intermediate oxidation. The boiler is only needed for startup, when the reactor is up to temperature the oxidation is thermally self-sustaining. The unit operates 24 hours per day, seven days per week. Acid washing is necessary every 6 to 7 days because of scale problems caused by sea water infiltration. One hundred pounds of soda ash is added each day to the sludge storage tank before the reactor to help control this problem. The plant was out of service for rebuilding the heat exchanger and compressor during CWC's inspection. The Blind Brook Plant is scheduled for expansion to an activated sludge plant. When expanded, the Zimpro plant will be shut down and sludge will be pumped to another treatment plant which is expected to install a Zimpro low oxidation process. The heat treatment decant and filtrate are discharged to an effluent wet well downstream of the chlorination basin. The recycle streams are considered disinfected and, therefore, are allowed to go directly into Long Island Sound via the plant outfall. The off-gases are bubbled into the same effluent wet well. The plant is located near homes and a recreational park, but there have not been odor complaints. The dewatered solids are hauled to a landfill.

Rockland County, New York

The Rockland County activated sludge sewage plant is located near West Nyack, New York. The intermediate oxidation Zimpro plant conditions primary and secondary sludge. The sewage flow presently exceeds the plant rated capacity, however, return of the supernatant and filtrate from the sludge conditioning to the head of the plant does not upset the plant. This is due to a high volatile solids reduction, around 90 percent, with the intermediate oxidation plant. The heat treatment operated fairly steadily from startup in summer 1969 until late 1973 before a series of lengthy down periods due to mechanical problems and lack of parts began. The main problems have been with the boiler and its feed pump, the air compressor, and the heat exchanger. Control of odors from the oxidized sludge tank has been a difficult problem. The district has used several gas burners, but with low temperature or installation problems. The district was installing a new unit which will have an exhaust temperature of 1500°F, and will be equipped with a heat exchanger to recover 55 percent of the heat and raise the incoming air to 780°F.

Groton, Connecticut

The Fort Hill Water Pollution Control Facility of the town of Groton has recently installed a BSP thermal sludge conditioning process for its new activated sludge plant. During the present very low flow conditions, the heat treatment is used only periodically to condition both primary and secondary sludge. Supernatant and concentrate are returned to the head end of the plant without incident. The decant tank is vented through an afterburner for off-gas treatment. All of the heat treatment and dewatering equipment is within a sludge handling building. There have been no odor complaints, although a strong odor is noticeable within the building while the thermal plant is running. The dewatered sludge is trucked to a landfill, but will be incinerated at the plant in the future when the quantities of sludge are larger. The heat treatment piping was originally designed as cast iron, but was changed before installation to glass-lined ductile iron to avoid corrosion problems.

Gloversville and Johnstown, New York

The joint wastewater treatment plant of Gloversville and Jonstown has a Zimpro low oxidation heat treatment process for primary and secondary sludge conditioning. The sewage contains discharges from many industries, including 22 canneries. The wastewater volume is 57 percent industrial, with a BOD of 550 mg/l and a suspended solids of 700 mg/l, 70 percent volatile. The treatment plant has primary sedimentation, high rate roughing trickling filters, followed by activated sludge. The heat treatment plant operates 24 hours per day, seven days per week, but shuts down every 10 days for acid washing. During the first three years of operation, forced plant shutdowns equalled 40 percent of the time. There have been less shutdowns during the past year. Heat exchanger scaling and mechanical repairs caused the shutdowns.

The supernatant from the oxidized sludge tank has been recycled to the roughing filter, as originally designed, and also to primary sedimentation and the aeration tanks without upsetting the plant. However, because of odors emitted by the supernatant it is not desirable to expose it to the atmosphere on the filters. Sometimes the oxidized sludge does not decant well and the supernatant contains up to one percent fine solids. Therefore, because of odor emissions and fine solids, the supernatant at present is discharged directly to the river without treatment. The filtrate is returned to primary sedimentation.

The odor problems were analyzed in a recent engineering report. This report claims the major source of odors is from aftergrowths in the oxidized sludge tank. The tank is essential for plant operations because oxidized sludge must be held 24 hours to thicken it sufficiently for vacuum filtration. Tank cleanings and the introduction of biocides to the sludge have not been successful in preventing these odors. Presently one barrel per day of peroxide is added to the tank for odor control. Off-gases from the tank are treated in a two stage scrubber, the first stage uses sodium hydroxide and the second stage uses hypochlorite.

Cincinnati, Ohio

The Muddy Creek Treatment Plant of the Metropolitan Sewer District of Greater Cincinnati has installed a BSP thermal sludge conditioning process. Primary and waste activated sludge is conditioned for vacuum filtration and incineration. The recycle streams are returned to the aeration tanks. Since the plant is operating at one-half of design capacity, there is no upset in the aeration process. The off-gases from the decant tank are passed through an afterburner at 1400°F. Little odor can be detected near the afterburner stack. The heat treatment plant has operated only five months in the 2 1/2 years since its initial start-up. At the time of inspection the plant had been down seven months waiting for a new boiler installation. The downtime has resulted from many mechanical, piping and instrumentation problems which has resulted in replacement of many items of original equipment.

Indio, California

The Valley Sanitary District's activated sludge plant at Indio uses a Zimpro low oxidation plant to heat condition its primary sludge. The heat treatment plant has operated reliably since 1969 with a minimum of downtime. Acid washing of the heat exchanger is required only once every year or two. The plant is operated eight hours per day, five days per week. The heat exchanger and separator are flushed out with each shutdown. Secondary effluent is stored in a secondary lagoon and then pumped to pasture irrigation. Waste activated sludge, Zimpro supernatant, and filtrate are discharged to an aerated lagoon for treatment. Overflow from the aerated lagoon is blended with secondary effluent for disposal. There is no recycle from the Zimpro process to the activated sludge plant. Off-gas from the heat treatment process are discharged at a three foot depth in the aerated lagoon. There is no odor problem at the plant. Dewatered sludge is taken by a private fertilizer company and blended with manure. Analysis by the District for fiscal year 1974-75 determined the total operations and maintenance cost to be $37.20 per ton.

Clark County, Nevada

The trickling filter plant of the Clark County Sanitation District, near Las Vegas, has recently installed a Zimpro low oxidation heat conditioning process. Primary sludge and trickling filter humus will be heat treated, vacuum filtered and incinerated. Heat treatment supernatant and vacuum-filter filtrate will be given fourteen hours aeration before recycle to the head-end of the plant. Off-gases from the decant tank, vacuum filters and thickeners will be burned at 1200°F.

South Milwaukee, Wisconsin

South Milwaukee has a batch operated Zimpro intermediate oxidation heat treatment for its activated sludge plant. The plant produces primary and secondary sludge which includes a phosphorus sludge produced by the addition of sodium aluminate. The sewage flow is 3 mgd. All the sludge is anaerobically digested. The Zimpro process handles two-thirds of it with most of the remainder hauled directly to land disposal and with a small portion going directly to drying beds. The heat treatment plant began operation in 1961 and was modified to batch operations in 1965. Each batch is about 5,700 gallons of digested sludge at about three percent solids. The sludge is pumped to a storage tank and from there transferred to the reactor with a low pressure centrifugal pump. Steam is injected to the reactor until the temperature reaches 400°F. Compressed air is added to the bottom of the reactor to 500 psi. Air and steam addition continue for 16 to 19 hours, then reactor pressure is reduced to 180 psi, the steam is then diverted to the storage tank to preheat a new batch of sludge and the reactor contents are discharged to a lagoon for drying. The continuous stream of off-gases from the reactor are diffused into the primary tank effluent channel. There is no dewatering equipment, decant liquor from the lagoon is returned to the primary tank and the sludge from the lagoon is removed to a landfill. For 1975 South Milwaukee has determined that the operation and maintenance costs for its heat treatment process were $87.30 per ton of dry solids.

Rothschild, Wisconsin

The small activated sludge plant at Rothschild is operated by Zimpro. A low oxidation Zimpro plant built in 1969 conditions the primary and waste activated sludge. Experimental work on heat treatment, recycle disposal, and odor control is conducted on this 6.7 gpm plant. Dewatered sludge is disposed of in a landfill.

Merrill, Wisconsin

Zimpro operates a thermal conditioning plant at the Merrill activated sludge plant. This heat treatment plant is similar to a Zimpro low oxidation plant except that no air is added to the reactor. The 25 gpm plant began operation in 1974 and operates at 300 psi and 390°F. Primary and waste activated sludge are processed. Dewatered sludge is hauled to a landfill. Off-gases are treated within a jet impingement scrubber and with ozonation.

Wausau, Wisconsin

Wausau has installed a Zimpro low oxidation heat treatment at its activated sludge plant. The heat treatment began operation in 1969 and processes primary and waste activated sludge 24 hours per day, five days per week. The plant operated with the air compressor out of operation in the summer of

1975. Without air addition severe odor problems developed. Also air addition improves heat transfer because of turbulence. The odor control is through an afterburner at 1200°F. Dewatering is done by a filter press supplied by Zimpro. Five thousand four hundred pounds per day of lime-alum water treatment plant sludge is added to the 10,800 pounds per day of sewage treatment plant sludge. The decant tank overflow is returned to the head end of the plant and the press filtrate is returned to the secondary part of the plant. Filter press cake is disposed of on the land or to landfill.

Terre Haute, Indiana

Terre Haute has a Zimpro low oxidation sludge conditioning process at its activated sludge plant. Seventy percent of the sewage flow is industrial and commercial, however, the BOD and suspended solids are in the normal municipal range. The 16 ton per day plant treats digested primary and waste activated sludge. Oxidized sludge supernatant and filtrate are returned to the primary tank and dewatered sludge is applied to the land at the plant. Off-gases are treated in a burner which has a maximum temperature of 1000°F. A higher temperature or a catalyst is needed to reduce the odors. In 1974, 110 tons of solids were processed and plant downtime was 208 days. In 1974 costs per ton of solids were determined as: Capital - $9.23, Operations - $23.46, and Maintenance - $83.60 for a total cost per ton of $116.29. The extensive downtime in 1974 was due to equipment failures, scaling of piping and heat exchangers, and delays in obtaining parts.

Denton, Texas

Denton has installed a Zimpro low oxidation heat conditioning process at its 6 mgd activated sludge plant. The heat treatment processes primary and waste activated sludge. After heat treatment the sludge is cooled in a tank and discharged to sand dewatering beds. The filtrate from the beds is returned to the head end of the plant. Gas from the gas-liquid separator goes to a diffuser in the junction box and some gas from the holding tank goes to a waste burner. Sludge from the beds is trucked to a ranch for disposal. There has been a considerable amount of downtime and maintenance on the heat treatment process and plant records indicate that only about 10 percent of the sludge is processed through the heat treatment. Sewage flow to the plant is now 7.3 mgd and the City is considering a plant expansion. Indications are that the heat treatment process will continue to be used in an expanded plant.

Muskogee, Oklahoma

The City of Muskogee has a BSP-Porteous thermal sludge conditioning process at its two stage trickling filter plant. The 50 gpm plant, which began operation in mid-1972, processes primary sludge and trickling filter humus. Off-gases from the decant tank, centrifuge and screw conveyor are exhausted through an afterburner.

Gresham, Oregon

The activated sludge plant at Gresham has installed a BSP thermal type heat conditioning process. Primary and waste activated sludge are heat treated, decanted, and centrifuged. The present sewage flow is 3.8 mgd with the plant rated at 6 mgd capacity. Initial operation of the heat treatment was in 1973. The downtime for 1974 was estimated at 21 days. The increase in BOD to be removed due to recycled heat treatment supernatant and centrate is calculated at 41 percent. The increase in total suspended solids to be given heat treatment due to the recycled supernatant and centrate is calculated at 59 percent. Off-gas from the blending tank, reactor, and decant tank is exhausted through a burner at 1200°F.

Vancouver, Washington

At 66 gpm BSP thermal type heat conditioning plant began operation in 1974 at the Vancouver, Washington activated sludge plant. Primary and waste activated sludge are heat conditioned, vacuum-filtered and incinerated. The increase in BOD to be removed due to recycled heat treatment supernatant and filtrate is 35 percent. There is an eleven percent increase in total suspended solids to be given heat treatment due to the recycled heat treatment supernatant and filtrate. Decanted heat treatment liquor and filtrate are returned to the primary tank. In 1974 2,782 dry tons of sludge were processed. The cost for heat treatment was $37.65 per dry ton and the cost for incineration was $9.64 per ton.

Portland, Oregon

Portland has two BSP thermal treatment units at its Columbia Boulevard activated sludge plant. Primary and waste activated sludge are heat treated, vacuum-filtered and trucked to a landfill. Estimates of the increase in BOD to be removed due to recycled heat treatment supernatant and filtrate are 16-28 percent. The increase in total suspended solids to be given heat treatment due to recycled supernatant and filtrate is 16-28 percent. Off-gases from the reactor are burned at 1200°F, other off-gases are ozonated. Heat treatment downtime is estimated at 33 percent for unit no. 1 and 30 percent for unit no. 2.

Colorado Springs, Colorado

Colorado Springs has installed two BSP-Porteous thermal sludge conditioning units. Colorado Springs has two sections to its secondary plant, 14 mgd of trickling filters and 30 mgd of activated sludge. One heat treatment unit handles primary sludge and trickling filter humus, the other unit handles primary and waste activated sludge. The first unit began operation in 1968 with the trickling filter plant and the second unit began operation in 1973. Downtime on the first unit is 30 percent and on the second unit 33 percent. The increase in BOD to be removed due to recycled heat treatment supernatant and filtrate is 21 percent. The increase in total suspended solids to be given heat treatment due to recycled supernatant and filtrate is 30 percent. Heat treatment affects plant costs by increasing the aeration time to 8 hours instead of six and adding 12 percent to the power consumption. The color of the final plant effluent is increased 60 to 100 standard color units. For the first five months of 1975 heat treatment costs per ton of dry solids were: Operation expense - $37.28, Operation labor - $14.24, and Maintenance labor and expense - $7.26.

EXPERIENCE SUMMARY

As a result of many field inspections and analysis of the data obtained, several aspects of thermal conditioning of sludge may be reviewed. It may be important to record comments gained as a result of this study, realizing that opinions may vary on these technical matters. An observation may come from the opinions of operators at only a few locations or from a problem unique to a location. The time and resources available for this study have not allowed verification of all these comments. The amount of information available to the design engineer when considering thermal conditioning of sludge is not large, therefore, even though all comments cannot be fully documented, they may be of value in putting the process in perspective.

Design

Pilot plant operation before design, regardless of size, appears to be desirable because of the large number of variables. Pilot plant operations may point up problem areas which should be given special consideration in design and also may provide special design criteria.

The basic criterion of design is the sludge flow rate. This flow rate determines detention time in the heat exchangers which should remain constant. The weight of sludge treated in a day is dependent on the hours of operation and influent solids concentration.

Heat treatment plants do not seem to be economical in small sizes. At small scale the comparatively high cost of support equipment such as boiler, air compressor, and decant tank makes heat treatment facilities more costly to build than other sludge treatment plants. Operations are expensive because of the constant attention required by a skilled operator. Also, the necessary operational skill might not be available to a small plant.

Multiple support units with interconnecting piping should be provided. The most essential units are the sludge feed pumps, grinders, high pressure pumps, and boilers. Without these units the plant cannot be run, therefore, there should be at least two units with one unit adequate to run the plant. For the Zimpro equipment it is not absolutely essential to have a backup air compressor since the plant can be run without air addition, as a thermal plant. Multiple reactors or heat exchangers are not necessary and, in fact, may not be desirable because the smaller reactors may be less stable thermally. A service life of 10 to 20 years is projected for piping and reactors constructed of proper materials. Zimpro's current design practice is to use No. 360L stainless steel throughout the piping, reactor vessel, and valving. Carbon steel does not appear to have sufficient corrosion and erosion resistance. One plant has installed glass-lined ductile iron. Where chlorides are high, Zimpro has installed titanium in its heat exchangers (chlorides greater than 400 mg/l). High chlorides are found most often where there is sea water intrusion. Some plants have been shut down for extended periods due to a lack of parts for the boiler water feed pump, and it is recommended that spare parts should be kept at the plant for this pump and all other essential mechanical items.

Grit removal must be provided for the raw sludge. The raw sludge grinder is a troublesome unit, requiring frequent maintenance. The grinder should be protected as much as possible from grit, large objects, trash and rags. The Zimpro low oxidation units are designed to operate with the addition of air. They can be used without air as thermal sludge conditioners, however, the fuel consumption is substantially increased. The Zimpro Company representative stated that operation without air would double the boiler fuel consumption. The other effects of air addition were less readily observed. Based on the plant visits, it appears that air addition does beneficially affect the odor of the off-gases, the strength and odor of the recycle stream, and the dewaterability of the sludge.

It is important to have the oxidized sludge storage tank equipped with decanting facilities. The oxidized sludge thickens readily to more than 10 percent in the storage tank. This improves the dryness of the filter cake and decreases the size of filters required.

Influent Sludge

In the low oxidation units, a higher sludge concentration is more desirable because less steam is needed. Many plants operate with a 3 percent solids concentration, however, six percent is more desirable. It is better not to digest the sludge before heat treatment as this affects the dewatering of the treated sludge. The breakdown of solids materials in the digester means a low filtering rate and a thin cake. Thermal conditioning of sludge is intended to treat the scum as well as the settled sludge. Generally plants experience no problems with scum treatment, however, in one plant where the raw waste had a high grease content from food processing, the operator was concerned with grease build-up from cycling through the thermal treatment.

Operating Conditions

The reactor temperature and pressure affect the amount of recycle BOD and dewaterability of the oxidized sludge. In general temperature should be kept as low as possible, consistent with adequate conditioning of the sludge. Higher temperatures breakdown the sludge particles, solubilizing more BOD and decreasing the fibrous material in the sludge which is essential to high filtration rates and thick cakes. The temperature and pressure of the reactor varies through the day especially where the plant is only run part of each day or where the raw sludge concentration varies considerably. Therefore, the temperature and pressure reported in the data tables, indicates the average point around which there is some variation.

Thermal treatment units always have an operator in attendance when they are running. The lead operator of the thermal conditioning crew should be machinery oriented and able to do routine frequent preventive maintenance. With proper preventive maintenance, some units have run years without significant problems. It is possible that a separate maintenance staff can care for the equipment, however, in plants where the chief operator takes the lead in maintenance work there seems to be fewer problems.

Maintenance Problems

The need to clean the heat exchanger is the most frequent reason for routine shutdown of thermal treatment systems. Scale builds up in the heat exchanger tubes and is removed, in some systems, by recirculating hot nitric acid through the tubes for about a day. The frequency of acid washing is highly variable, some plants requiring it every week to two weeks and other plants run 26 weeks before requiring acid wash. The frequency of acid washing seems related to the hardness of the water in the service area. Scale is removed from the reactor less frequently and some times this is done by hand chipping.

A major overhaul of mechanical equipment should be expected every five to eight years. This would include, major work on the air compressor, high pressure pumps and boiler. More frequent overhaul of the grinder is to be expected and the boiler may also need more frequent attention depending upon the feed water chemical quality and chemical conditioning.

Odor

The existence of odor problems seems to be a highly individual matter. Some plants operate without odor control equipment without complaint, yet others have severe problems due to odors. Site conditions are an important factor in the determining the extent of odor control equipment required. The proximity of housing to the plant, local topography, and wind and atmospheric conditions in the area are important in considering the odor potential at a given plant. The most severe odor problems are with the off-gas from the gas-liquid separator and the decant tank. The recycle liquor may also be odorous. The off-gas can be successfully treated. The most frequent method is to use high temperature incineration (1,500°F). The operation of the incinerator requires about as much fuel as the steam boilers and, therefore, may not be possible in some gas short areas. The substitution of fuel oil to operate the incinerator may also be costly. The current recommended odor treatment procedure by Zimpro is to treat off-gas in a dry packed granular carbon tower where the carbon is regenerated with steam. The air flow through the decant tank is about doubled over that of process air to provide more rapid air changes in the tank. Liquid scrubbers with caustic, permanganate, or chlorine have also been successful. In certain cases, off-gas is merely bubbled through a tank or lagoon of chlorinated effluent. The results with ozone treatment are less clear, some operators claiming success with that type of treatment and others saying they had tried it and it did not work. Low temperature catalyst odor treatment has not been successful. Conversion of low temperature units to high temperature operation has generally not been successful because of the inadequate gas capacity and overheating of the stack.

Supernatant-Filtrate Recycle

The BOD of the recycled liquors from the thermal treatment system can constitute a substantial overload on a wastewater treatment plant not originally designed with surplus aeration capacity. The recycle BOD load can be about 20 percent of the influent BOD load on the aeration system. The hydraulic recycle loading on the plant, however, is very small and generally can be ignored. The recycle liquor can be introduced at the head end of the plant which is most common or at the aeration tanks. The BOD is almost all soluble. There are some situations, however, where solids capture on vacuum filters is poor, and fine solids are returned to the plant. If this situation continues, there can be a buildup of solids in the plant which settle in the final clarifiers, are returned to the heat treatment and from there returned to the treatment plant in the filtrate. Waste biological solids produced from the recycle soluble BOD are equal to a net yield of about 0.6 lb waste activated sludge per lb of recycled BOD.

Most plants visited were operating at less than design load, therefore, they had adequate aeration capacity available to treat the recycle loads. In most cases, the operators did not feel there was extra labor involved in recycle treatment although they did acknowledge that extra blower power may be required to treat the BOD.

Color in the effluent appears to be variable. Some plants are concerned with it, most plants, however, do not consider it a problem.

Chemical Analyses

Only a minimum of chemical testing information is available from plant records. Plants do not routinely test their heat treatment streams because they feel data are of relatively little use to them for purposes of process control and the tests are difficult and time consuming for the average plant laboratory.

SECTION VIII

DIRECT AND INDIRECT COSTS OF THERMAL TREATMENT OF SLUDGE

GENERAL

This section presents information, estimates, and curves for the cost of thermal treatment plants. Subsections cover construction, operation, and maintenance costs for the thermal treatment process itself, the handling and treating of strong liquors from the treated sludge decanting tank and dewatering equipment, and the treating of odorous gases.

As discussed in Section III, information related to costs of thermal treatment was obtained from several sources including surveys of operating plants, review of available literature and manufacturers' data, and preparation of engineering estimates. The surveys and the manufacturers' data yielded much information on direct costs although in many instances some conversion was required to put the data into a form usable for this study. Very little information on the indirect costs of or requirements for treatment of liquors and off-gas was forthcoming from the surveys. Engineering estimates, information from the literature review, and information from manufacturers were used almost exclusively to arrive at the indirect costs.

The costs are presented in various ways. First, costs for thermal treatment alone or for its components are compared with the physical variable most controlling for the particular cost. The separate listing of items such as materials, fuel and labor, which vary with time and location, provides a base for adjustment to local conditions. Costs for the various components were combined and expanded to plot thermal treatment costs versus wastewater treatment plant size for a typical wastewater and plant. These generalized cost curves provide a quick preliminary estimate of the approximate total cost of thermal treatment.

CONSTRUCTION COSTS (THERMAL TREATMENT)

In order to estimate the costs to construct thermal treatment facilities of various capacities, construction cost data were obtained from the records of approximately thirty thermal treatment plants, from manufacturers, and from engineering estimates. Bidding information and records from plants frequently did not contain breakdowns indicating what portions of the cost were for thermal treatment and, where some breakdown was provided, it often covered the total costs for sludge handling and included prethickening, storage, thermal treatment, decanting, vacuum filter or centrifuge dewatering, incineration, and engineering. Information from some plants included the costs for buildings, which were sometime quite elaborate, large, included room for expansion, and housed dewatering and incineration systems as well as thermal treatment facilities. Building costs for some plants were reported to be over two-thirds of the costs for thermal treatment equipment.

Because of these differences in reported costs, the costs for thermal treatment alone were separated for comparison and plotting. The resulting costs for thermal treatment include sludge feed pumps; grinders; heat exchangers; reactors; boilers; gas separators; air compressors where applicable; decanting tanks; standard odor control systems; and piping, controls, wiring and installation services usually furnished by the equipment or system manufacturer. Not included in the basic thermal treatment costs are buildings; footings; piping, electrical work and utilities not supplied by the equipment manufacturer; sludge storage and thickening prior to thermal treatment; sludge dewatering, incineration or disposal; land; and engineering fees.

The separate costs for thermal treatment are presented in terms of March 1975, national average costs. In escalating costs to later dates, it should be considered that the escalation determined from the EPA-STP index may not adequately reflect the increased costs for high temperature, equipment-dominated processes such as thermal treatment. Costs are plotted as cost per unit of thermal treatment capacity versus thermal treatment capacity ($ per gpm vs. gpm) in Figure 7 and as cost for thermal treatment versus thermal treatment capacity ($ vs. gpm) in Figure 8.

A second curve is plotted on each of the above two figures to include the costs for typical building, foundation and utility needs for the thermal treatment systems. The building costs represent single-story, concrete or masonry construction with built-up roofing, insulation and heat and vent systems, and assume that reactors and decant tanks will be located outside of the building. The costs also include piping and wiring within the building, foundations for internal and external equipment, and a limited amount of sitework. Building sizes provide for easy access to equipment and a control room. For larger installations, where multiple units are anticipated, space for some standby equipment is included. Typical building sizes range from 1500 sq ft for a 10 gpm plant to 5250 sq ft for a 200 gpm plant. The construction cost per square foot of building was estimated to be $36.

The curves show a rapid rise in unit construction costs for plants smaller than about twenty gallons per minute, indicating that there is a limiting plant size below which high cost may make the process economically infeasible. For large plants, above about 150 gallons per minute, the increased use of multiple treatment units and of standby units results in a lower limit for unit cost per gpm of capacity. This lower limit appears to be in the range of $9000 to $12,000 per gpm. Data for these larger plants are sparse, however, and some plants reported lower unit costs.

At the present time, the minimum direct cost of a thermal treatment plant is estimated to be approximately $350,000 regardless of plant size.

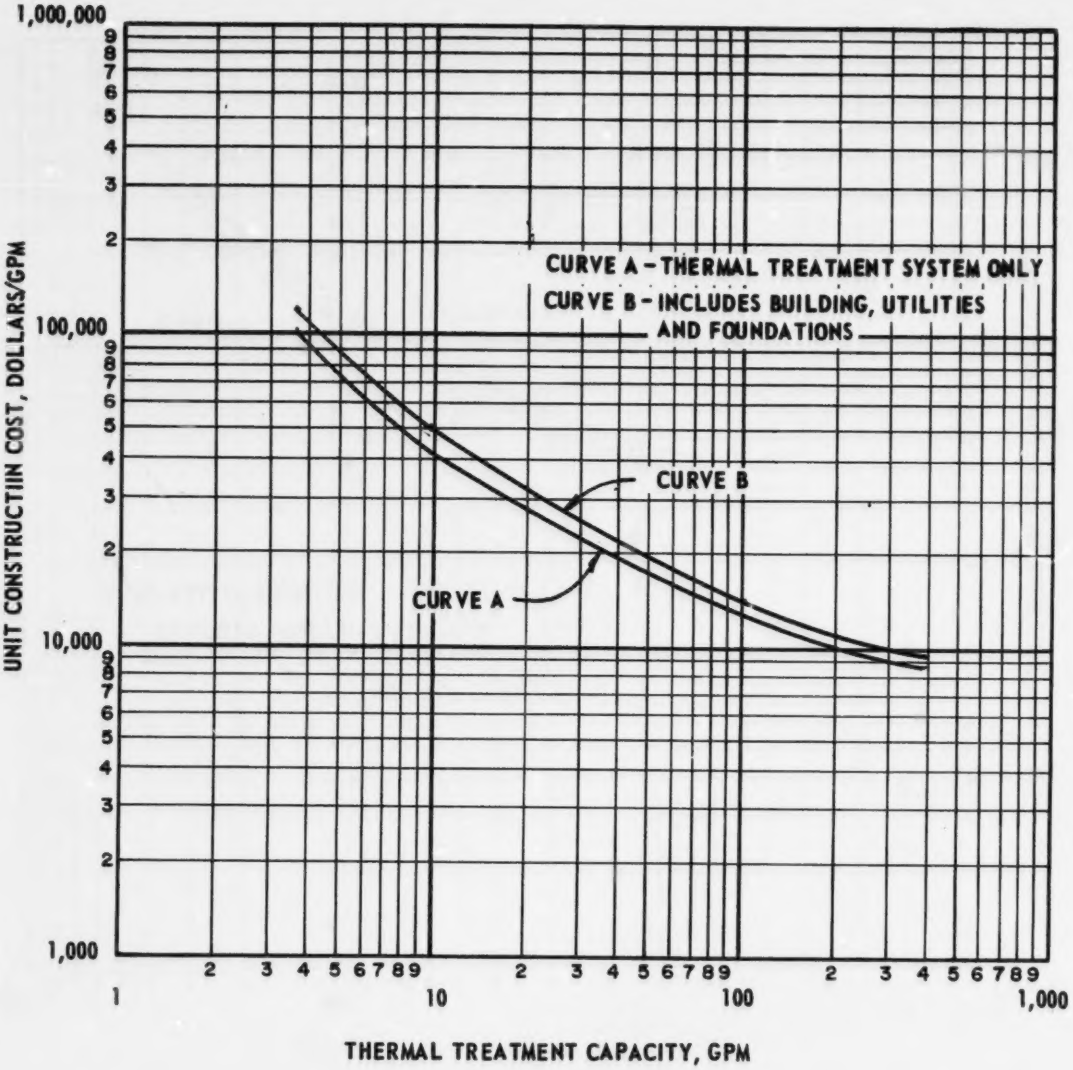


Figure 7. Direct unit construction costs for thermal treatment.

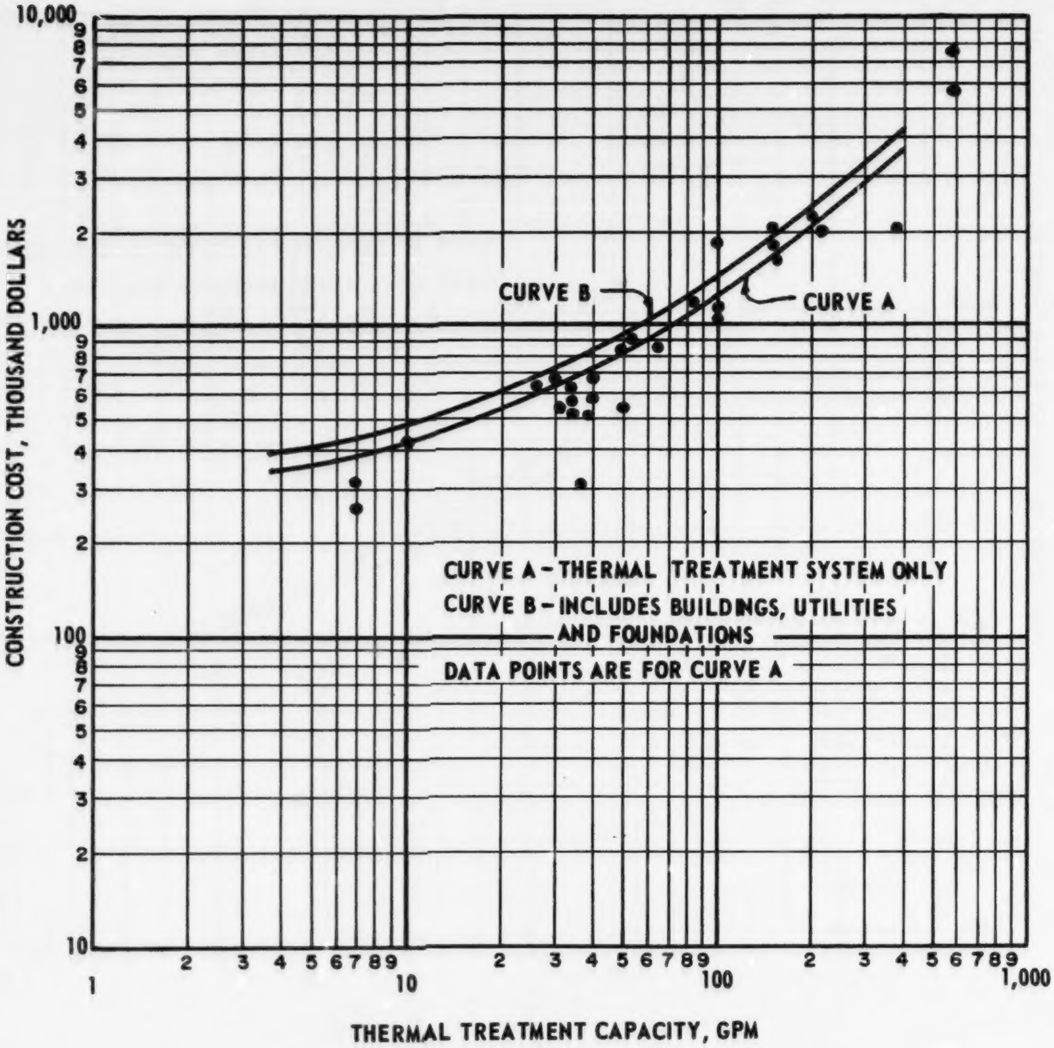


Figure 8. Direct construction costs for thermal treatment.

FUEL AND ELECTRICAL ENERGY REQUIREMENTS (THERMAL TREATMENT)

Fuel and electrical energy use and cost data were obtained from the records of several operating plants, from equipment manufacturers, and from calculations. For analysis and comparison, cost data again were reduced to unit requirements and then recomputed as costs based on common unit pricing. Because both fuel and electrical energy usages are dependent primarily on the volume of sludge processed, volume treated was used as the common denominator for both utilities. Fuel and electrical energy requirements were analyzed, respectively, as million Btu per gallon and kwh per gallon treated. Uniform unit prices and annual volumes were than applied to obtain annual costs.

Fuel is used chiefly as a source of heat to produce steam. The amount of fuel used is influenced by the temperature to which the reactor contents must be raised, the efficiencies of the boiler and heat exchanging systems, insulation or heat losses from the system, and the degree of heat-producing oxidation which takes place in the reactor. Some reduction in the unit heat requirement for an increase in plant size was noted in reported data. This is thought to result from more uniform and constant operation of the system, greater heat transfer and insulation efficiencies and possibly a greater amount of oxidation in the larger units. Plants adding air to their heat exchangers and reactors and experiencing some oxidation had lower fuel requirements. The annual fuel requirements based on 8000 hours of operation at capacity vs plant size are shown in Figure 9.

Typical fuel requirements averaged 900 to 1000 Btu/gallon for plants not practicing air addition and 300 to 600 Btu/gallon, depending on the degree of oxidation obtained, for plants practicing air addition. Curves in this report are based on fuel requirements of 900 Btu/gallon for thermal conditioning plants and 500 Btu/gallon, corresponding to about five percent oxidation, for low oxidation plants. The above fuel requirements do not include allowances for treatment of off-gas.

Electrical energy needs are determined by sizes and efficiencies of driven machinery such as sludge and boiler water pumps, grinders, thickeners and, in plants where air addition is practiced, air compressors. Electrical energy is also needed for lighting and other building uses. Because the majority of the plants investigated did not meter separately the energy used in the thermal treatment process, and there was substantial variance among the available data, supplementary estimates of electrical energy use were made based on typical equipment sizes and efficiencies. Average unit energy usages were found to be 22 kwh/10^3 gallons for plants practicing air addition and 10 kwh/10^3 gallons for plants practicing only thermal conditioning. Annual electrical energy usages for the two types of plants based on the same criteria as above for fuel are shown in Figure 10. A separate curve is included on the figure for estimating the energy requirements for building needs.

As can be seen, the electrical energy required for air addition is approximately equal to the remainder of the load for thermal conditioning. The curve also shows that for small plants, the load for miscellaneous building requirements is a substantial portion of the total plant load.

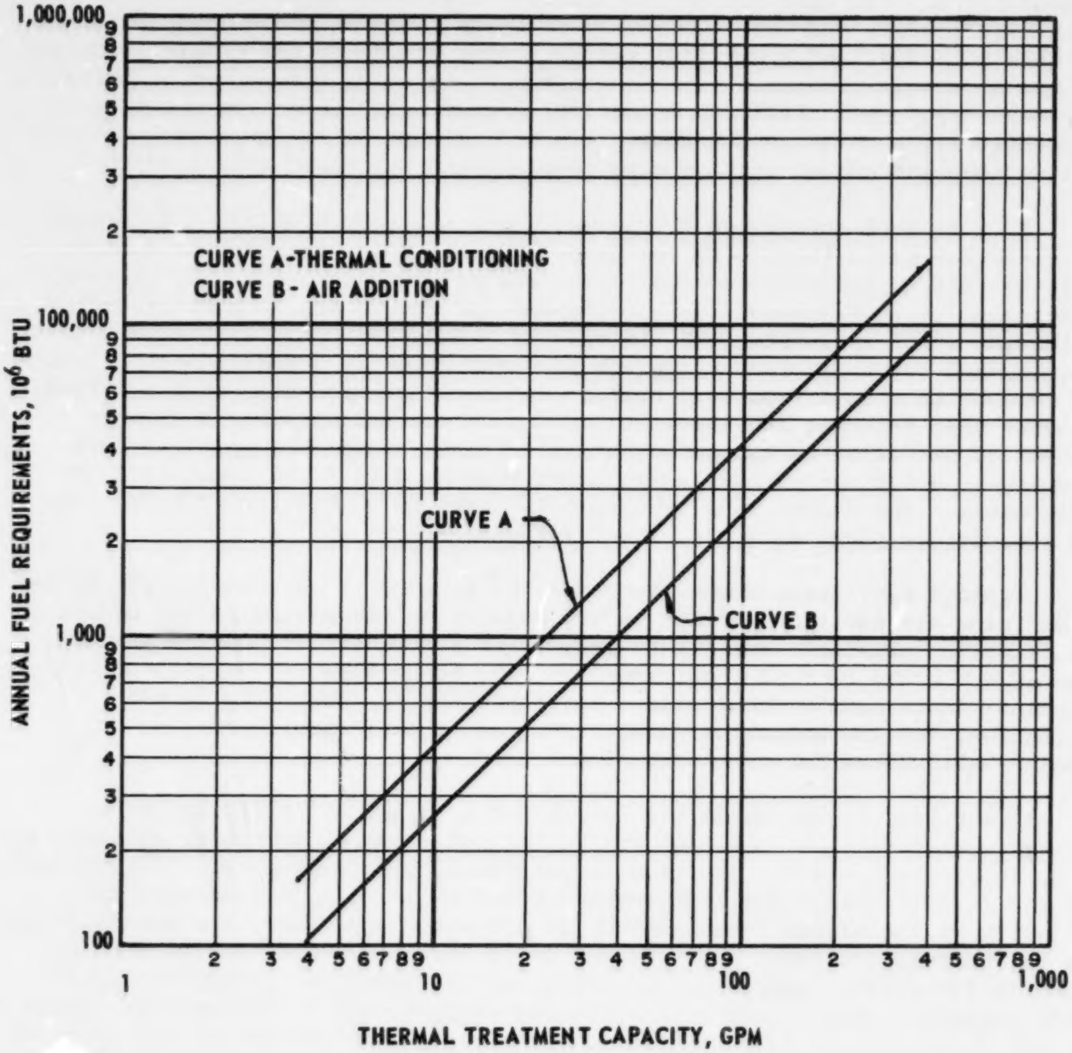


Figure 9. Annual direct fuel requirements for thermal treatment.

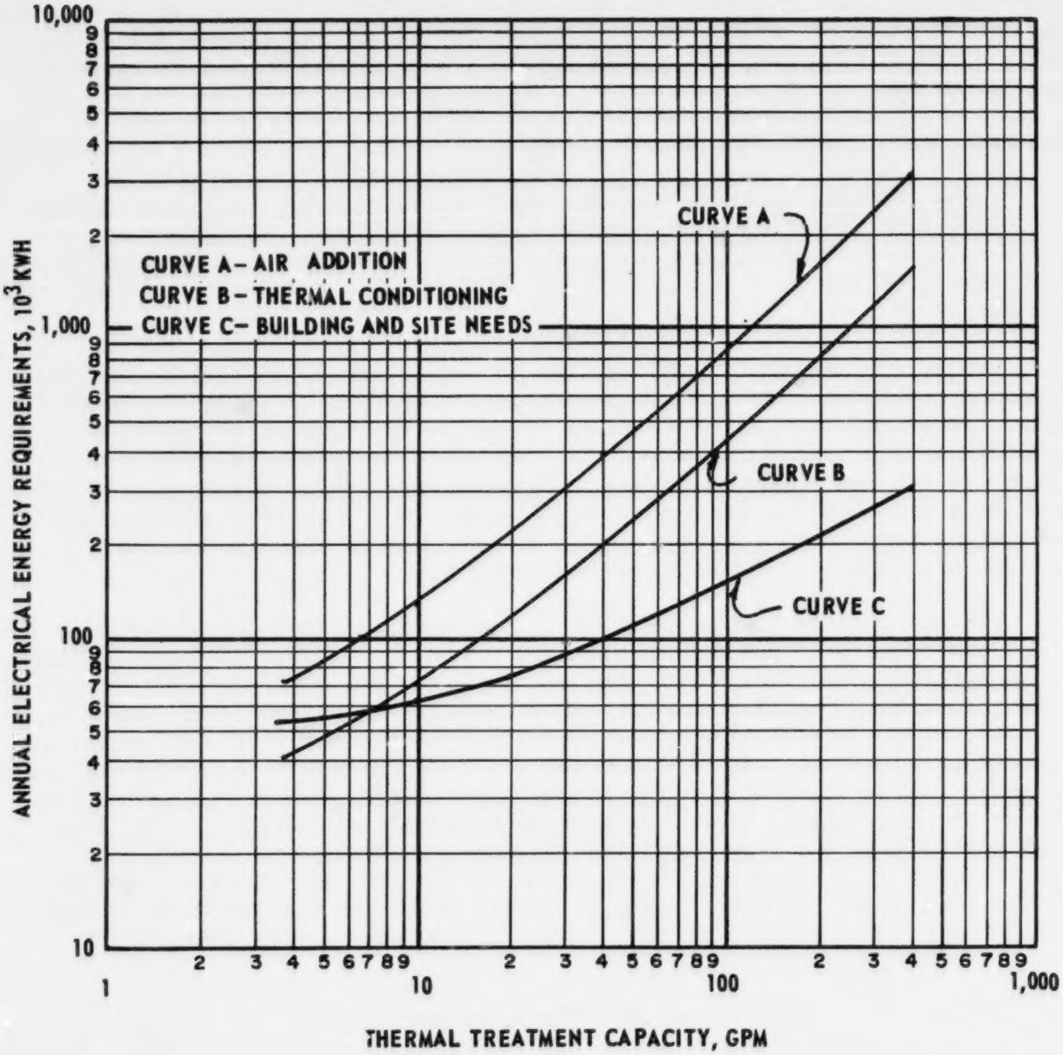


Figure 10. Annual direct electrical energy requirements for thermal treatment.

Annual costs versus plant sizes for both fuel and electrical energy are shown in Figure 11. To determine these annual costs, unit costs of $2.80 per million Btu for fuel and $0.03 per kwh for electrical energy were applied to the usages shown in Figure 9 and 10. These unit costs may appear high when compared with those reported by some plants visited. However, it is doubtful that low unit costs such as $0.01 per kwh for electrical energy and $1.00 per million Btu for natural gas some plants have reported will continue to be available.

MANPOWER REQUIREMENTS (THERMAL TREATMENT)

Labor for operation and maintenance presents one of the highest areas of cost in the operation of a thermal treatment plant. For plants below about 50 gpm the cost for labor exceeds the cost of energy. At 10 gpm the cost for labor may be in excess of two and one-half times the cost for energy.

Labor requirements can be divided into two types: operation and maintenance. In this study operation comprises time spent reading and logging data on the process, controlling and adjusting the various systems and components, and laboratory work. The functions covered by maintenance include cleaning and repairing process components, general upkeep of the process area, checking and repairing of controls and instrumentation, and performing preventative maintenance. In some plants these operation and maintenance functions may vary or may overlap.

For use in this study, labor costs and manhour requirements reported by plant operators were reduced to manhours per year based on an assumed 8000 hours per year operation of the thermal system. The labor requirements for maintenance and operation are plotted separately on Figure 12 as manhours per year versus thermal treatment capacity. Data and the figures show that for mid-sized plants, one operator per shift is employed. As the plant size decreases below about 40 gpm the operator can perform other duties as well as operate the thermal treatment plant. Reported data indicate that for small-sized plants the operator may also operate dewatering facilities or provide some of the maintenance required for thermal treatment. For larger plants more operation is required, reaching about two operators per shift at 200 gpm. Some plants, however, report using two or more operators at plants much smaller than 200 gpm.

Reported data on requirements for maintenance labor vary considerably from plant to plant and an average confirmed by calculation was used for plotting. In general, maintenance labor is approximately one-fourth of the operating labor, ranging from the equivalent of one maintenance man for one shift at a 50 gpm plant to one and one-half men for one shift at a 200 gpm plant. The amount of maintenance required depends greatly on the design and operation of the plant, particularly on equipment and materials used for construction. It is also dependent on the skill and knowledge of the maintenance personnel and the design of and adherence to a preventative maintenance program. Plants practicing a well designed maintenance program appeared to have less maintenance problems and to require less overall time for maintenance.

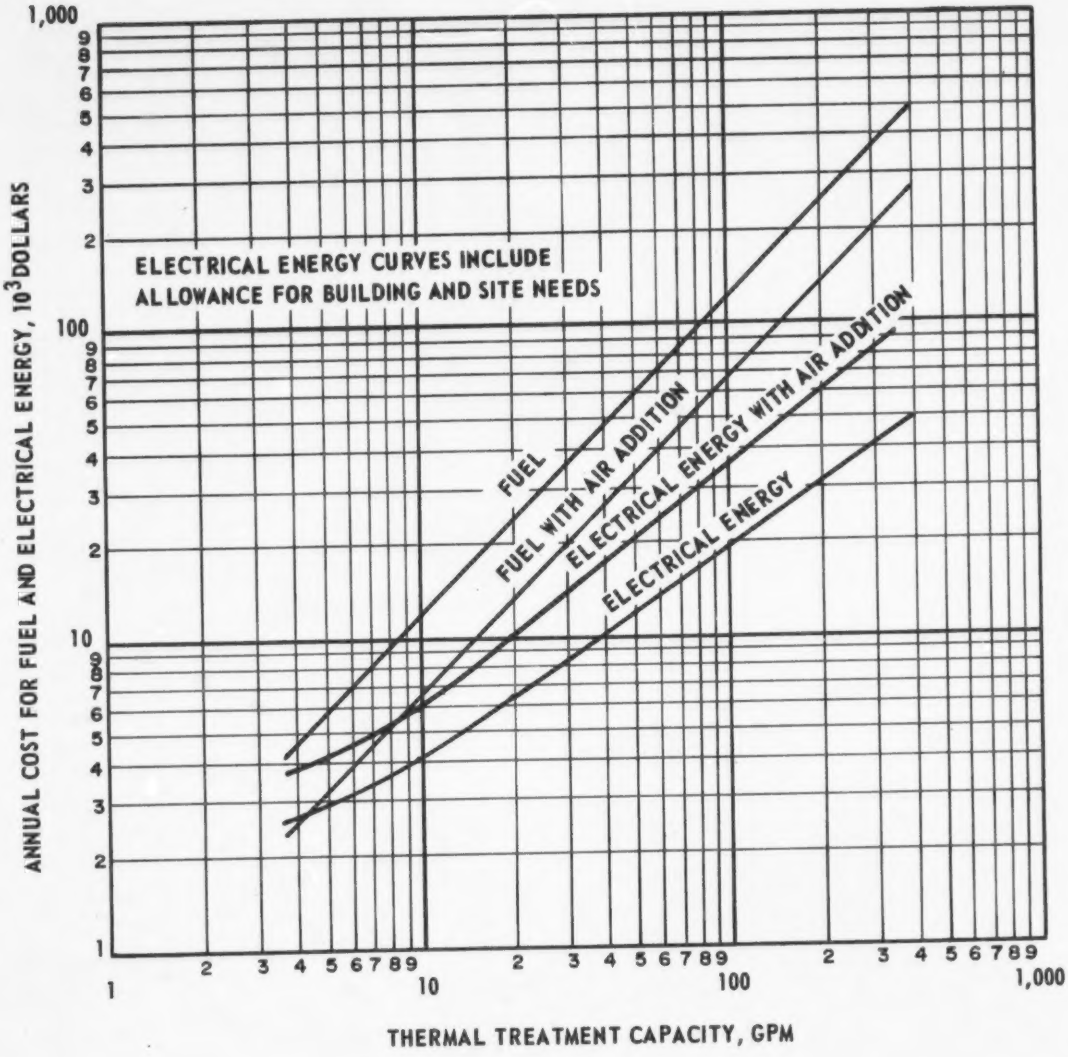


Figure 11. Annual direct cost of fuel and electrical energy for thermal treatment.

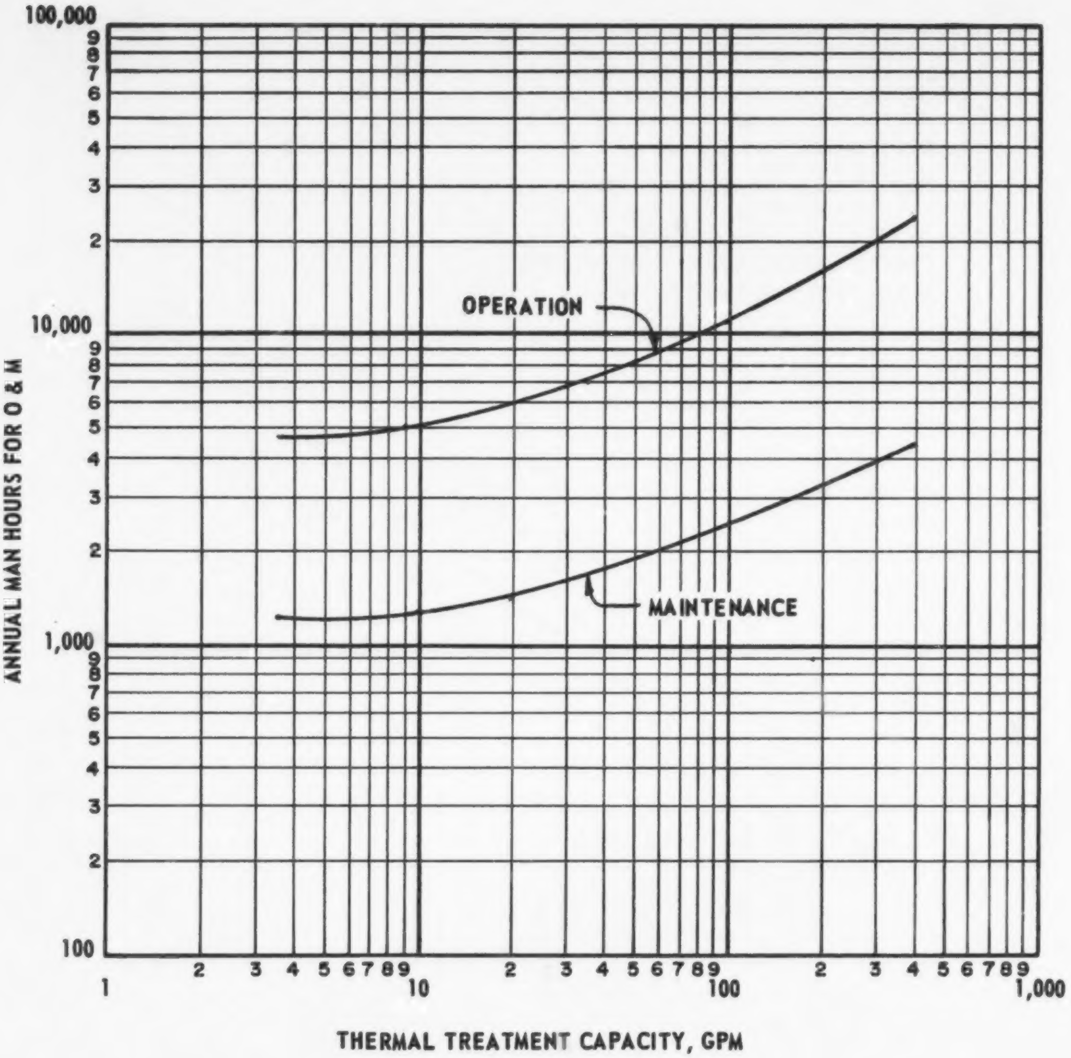


Figure 12. Operating and maintenance requirements for thermal treatment.

Maintenance as discussed above and as shown in Figure 12 is for preventative work and routine repair work. It includes daily clean-up, lubrication, replacement of seals and gaskets, acid or other normal cleaning of heat exchanger tubing, painting and similar work done on a daily, weekly, monthly, etc. basis. It does not include major overhal functions which should be accomplished on a periodic basis every six or seven years.

Labor requirements for major overhaul work such as reactor cleaning; pipe and tube replacement; pump, compressor and boiler working parts replacement and other similar items are not included in Figure 12. For this type of work, except in large plants, the skills of specially trained manufacturers' representatives or contracted specialists should be utilized. Costs for this work is covered below under "Materials and Supplies".

Figure 13 is included to indicate the manpower costs for thermal treatment. The graph is based on the hours reported in Figure 12. An average unit labor cost of $7.00 per hour is used for the extension. Hourly costs will, of course, vary with the particular circumstance of plant size and location. Based on the illustrative labor cost, the labor costs for thermal treatment vary from $0.08 per gallon for a 200 gpm plant to $0.17 per gallon for a 50 gpm plant to $0.56 per gallon for a 10 gpm plant.

MATERIALS AND SUPPLIES (THERMAL TREATMENT)

Annual costs for several reporting plants were summarized and are shown in Figure 14. Curve A shows the normal annual cost for materials and supplies required to operate and maintain the thermal treatment system. These costs are plotted against thermal treatment plant capacity and include materials and parts such as seals, packing, coatings, lamps, bearings, grinder blades, and other items used in scheduled and normal maintenance. They also include operating supplies such as lubricants, cleaning chemicals, boiler feed water, and water treating chemicals. These costs vary from about $5000 per year for a ten gpm plant to approximately $20,000 per year for a 200 gpm plant.

Besides the normal, periodic maintenance required for a plant and covered by Curve A, additional costs for major overhaul work are incurred. This work includes such items as motor rewinding; major overhauls of pumps and compressors; major, non-routine rehabilitation or replacement of heat exchanger tubing piping and controls; and refitting of boilers. This type of work is required at an average interval of about six to seven years, depending on the conditions at a particular plant. Because labor for this type of major work is often contracted, labor costs are treated as part of the overhaul and are included in its cost under this section. Curve B shows the combination of these costs with those included under Curve A to give the total annual cost for materials and supplies. The inclusion of major overhaul work increases the annual materials cost by about 45 percent over that required for routine and preventative maintenance materials.

There was considerable variation among the costs for materials in seemingly similar plants and it appeared that three factors tended to govern the costs. The first of these was the adequacy of the preventative

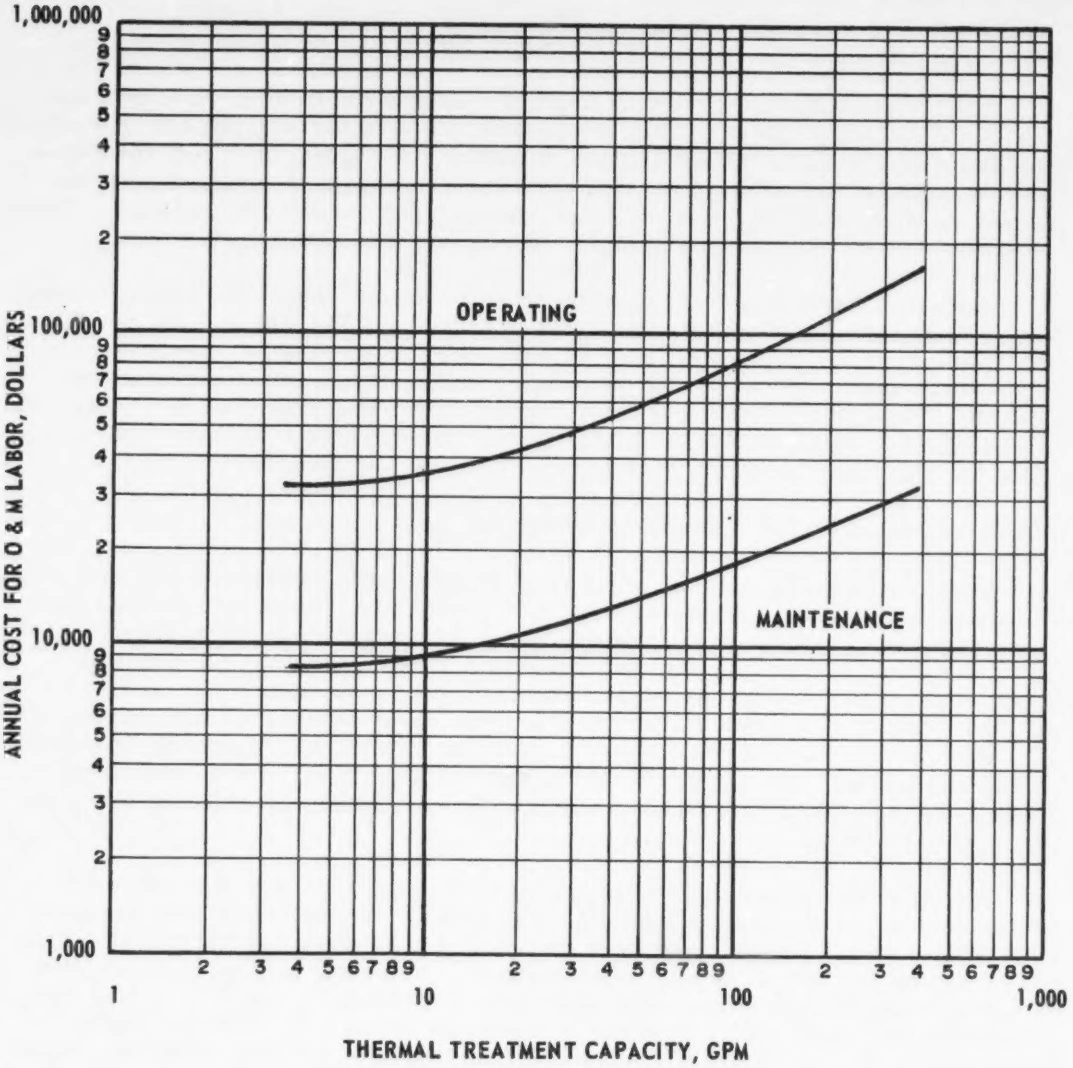


Figure 13. Operating and maintenance labor costs for thermal treatment.

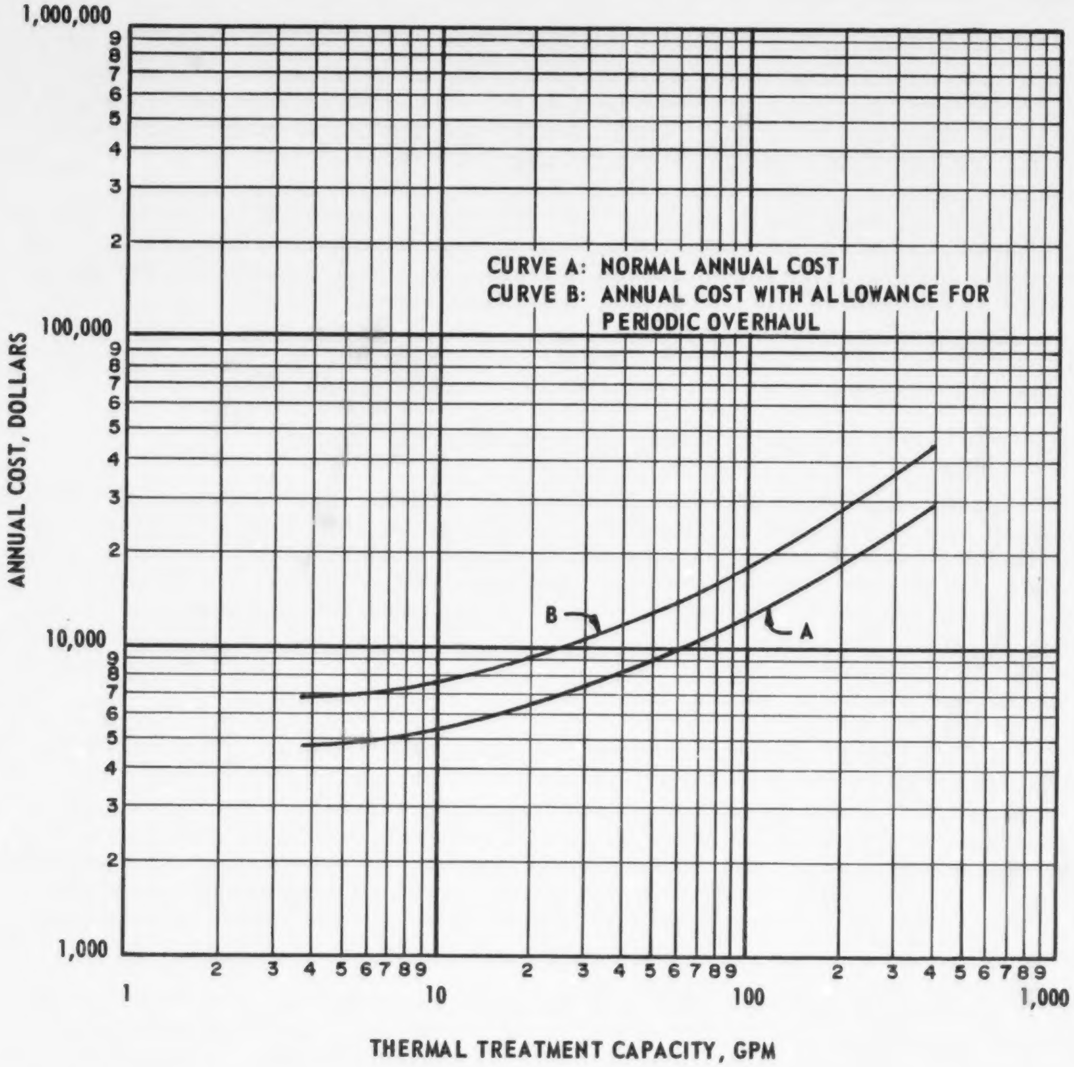


Figure 14. Materials and supplies for thermal treatment.

maintenance program. In plants where a good program was practiced, overall costs for parts and supplies generally were lower. Where maintenance was neglected, more major failures were found to occur with a need for greater expenditure for parts.

The second factor involved the design of the plant and selection of materials of construction. If a higher grade of materials and equipment were selected for initial construction and if the plant were designed with ease of maintenance in mind, less maintenance and better maintenance were found and hence less need for replacement was noted.

Finally, need for materials and supplies was affected by the quality of the area's water supply. In areas having high amounts of hardness and high mineral contents in their water supplies, more scaling and corrosion were noted in equipment, particularly in heat exchangers. Scaling, along with the increased amount of cleaning required, resulted in both an increase in replacement parts for boilers and heat exchangers and an increased amount of chemicals for boiler water treatment and heat exchanger cleaning.

INDIRECT COSTS FOR HANDLING AND TREATING RECYCLE LIQUORS

Costs associated with the handling and treating of the strong liquors resulting from thermal processing of sludge often have been neglected when comparing thermal treatment with other sludge conditioning processes. These costs can affect substantially the total cost of treatment. Depending on the method chosen to handle and treat the liquors, the characteristics of the liquors, the sewage treatment process, the discharge requirements and other factors, the costs for processing the liquors may reach 20 percent of the direct costs for thermal treatment.

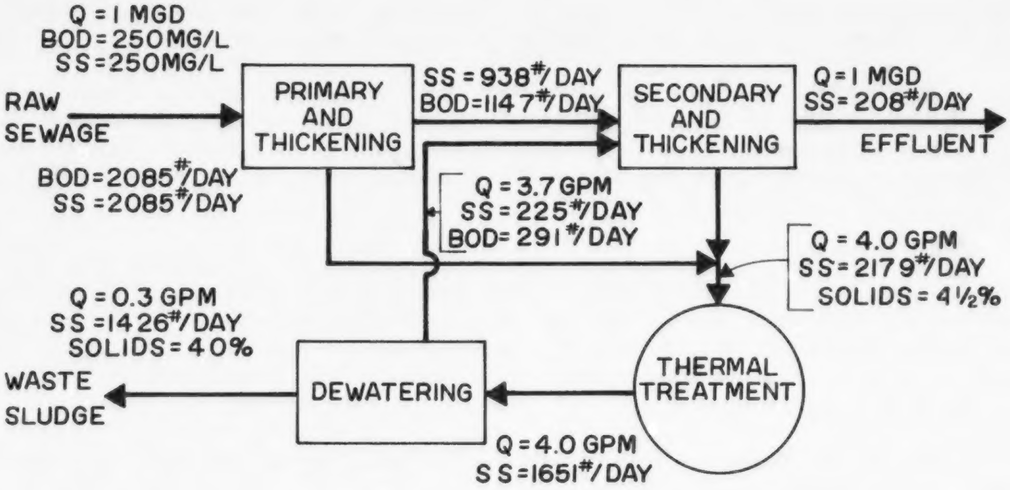
This section presents information for preparing initial estimates for comparison of processes. The information is presented in the form of graphs showing the cost of constructing and operating facilities to handle process liquors. The graphs are based on one of the many sets of conditions and processes which might be encountered or used in design of thermal treatment facilities. Many other sets of conditions could be encountered in actual practice and their costs can be estimated in a manner similar to that used herein.

The method selected considers direct recycle of liquor to the activated sludge section of the main treatment plant. This process was selected because it is the one most often used in the plants studied. A liquor quality of a BOD of 6500 mg/l, and a suspended solids concentration of 5000 mg/l (75 percent volatile) is used. It was also assumed that the incoming sewage to the plant has BOD and suspended solids concentrations of 250 mg/l each and is subjected to primary treatment prior to mixing with the recycled liquor.

Other conditions are that: (1) the process, prior to the addition of the recycled liquor, is fully loaded so that no capacity to accept the liquor remains, (2) the sizes of various equipment and structures in the process must be increased to maintain the same mixed liquor solids concentration and cell residence time, (3) the combined primary and secondary sludges are thickened to 4.5 percent solids prior to thermal treatment, and (4) slight degradations in effluent color, COD and BOD are acceptable.

Design calculations were made to size plant components before and after adding the recycled liquor. In this way, incremental costs and requirements could be estimated by comparing before and after values.

The illustration below shows the process and the amounts of solids flowing in various process streams.


Q = 1 MGD
BOD = 250 MG/L
SS = 250 MG/L
RAW SEWAGE
PRIMARY AND THICKENING
BOD = 2085#/DAY
SS = 2085#/DAY
SS = 938#/DAY
BOD = 1147#/DAY
SECONDARY AND THICKENING
Q = 1 MGD
SS = 208#/DAY
EFFLUENT
Q = 3.7 GPM
SS = 225#/DAY
BOD = 291#/DAY
Q = 4.0 GPM
SS = 2179#/DAY
SOLIDS = 4 1/2%
Q = 0.3 GPM
SS = 1426#/DAY
SOLIDS = 40%
WASTE SLUDGE
DEWATERING
THERMAL TREATMENT
Q = 4.0 GPM
SS = 1651#/DAY

SOLIDS AND FLOW DIAGRAM FOR A TYPICAL ACTIVATED SLUDGE THERMAL TREATMENT SYSTEM

Recirculation of liquor of the above stated quality results in an additional solids load on sludge processing facilities. This load is approximately 300 lbs per day per mgd of raw influent. The increase comes primarily from the nonvolatile and non-degradable fractions of the solids in the return liquor and from cell production from the recycled BOD. This load increases the amount of sludge to be processed by about 15 percent.

For the case under study, recirculation also increases the BOD loading to secondary treatment by 20 percent.

Treatment plant capacity was selected as the variable having the greatest influence on costs for liquor treatment. Other variables, particularly the BOD and suspended solids concentrations in the raw sewage, also influence the cost of liquor treatment but do not vary over as great a range as influent flow. Their use would also result in a more complex and difficult procedure for estimating cost.

Construction Costs (Liquor Treatment)

Construction cost for handling and treating liquors from thermal treatment was estimated for the above use. The estimate uses the same basis as was used earlier under direct construction costs and is taken primarily from Black and Veatch, "Estimating Costs and Manpower Requirements for Conventional Wastewater Treatment Facilities", EPA Project 17090 DAN, October 1971 (B&V). Construction costs taken from B&V are up-dated to March 1975 national average values.

The estimate includes costs for increasing the size of an activated sludge system using diffused-air for aeration. The only areas of significant cost increase is in the aeration tanks and air supply system.

Because the increase in hydraulic loading is very small, there is almost no increase in cost for clarification, piping and pumping. An allowance of 10 percent above the cost increase for aeration is provided, however, to cover those small costs and increases for site work, yard piping, utilities and support facilities.

Costs to provide sludge storage ahead of thermal treatment are not included in the differential cost. Such storage like many other items is common to treatment plants whether or not thermal treatment is used so that no differential would result. If the addition of storage is required, its cost can be easily estimated from various cost references and added to the costs developed herein.

Figure 15 shows the incremental cost for plant enlargement versus treatment plant capacity.

Energy Requirements (Liquor Treatment)

The indirect energy requirements to operate processing facilities for recycled liquor treatment were estimated for the same system as used for estimates of construction costs. Again, increments were determined based on the differences in operating requirements with and without recycled liquor included.

The increment in energy requirements results almost entirely from the increase in aeration capacity needed to treat the recycled liquor. Increases in energy requirements for other operations such as clarifier and thickener drives and pumping are negligible in comparison.

The requirements are shown in Figure 16 as kilowatt hours per year for 8000 hours of operation versus treatment plant capacity. The annual cost for that energy based on a unit cost of three cents per kilowatt hour is shown in Figure 17.

Manpower Requirements (Liquor Treatment)

The requirements for operation and maintenance labor needed for the sewage treatment facility expanded to treat the recycle liquor are shown in

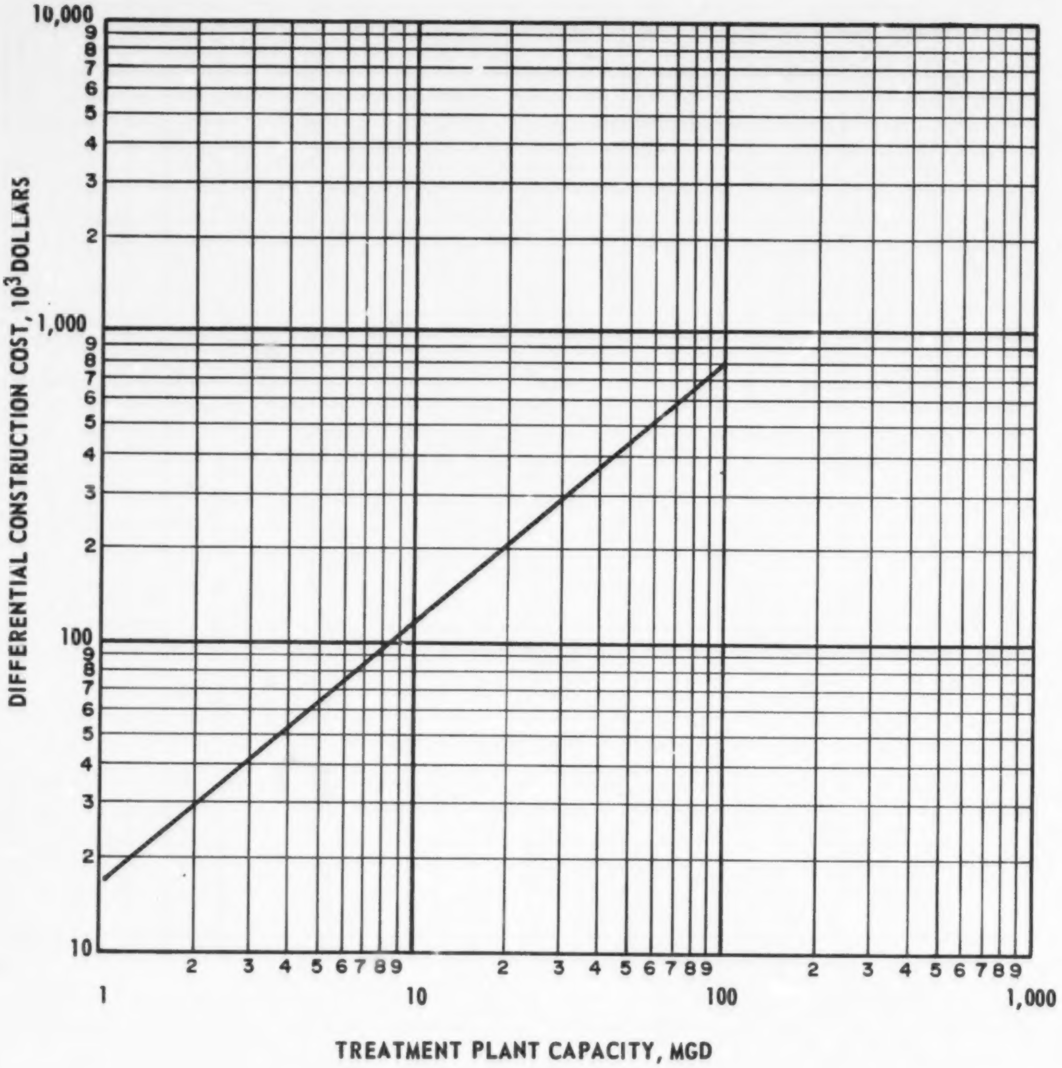


Figure 15. Incremental cost for construction of recycled liquor treatment facilities.

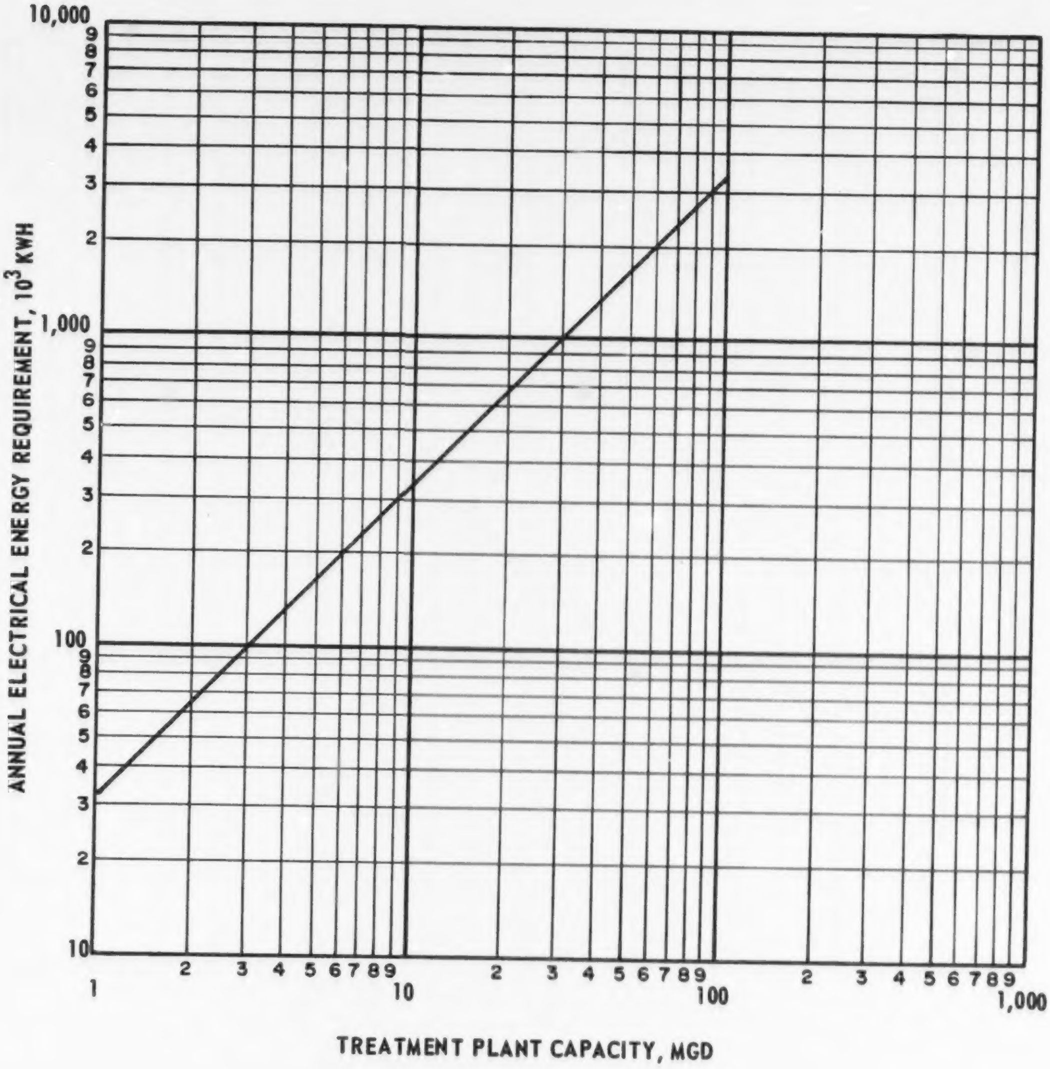


Figure 16. Incremented electrical energy requirement for recycled liquor treatment.

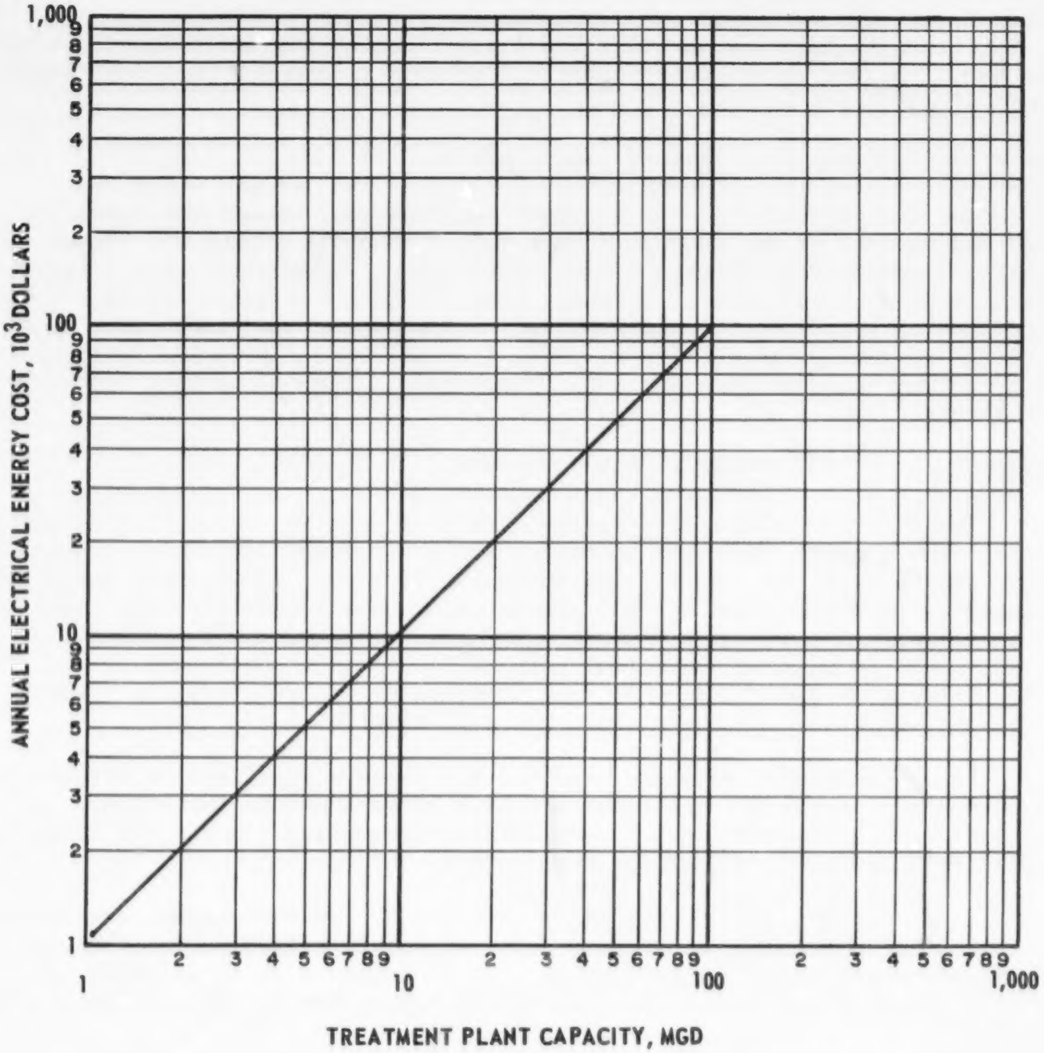


Figure 17. Incremental electrical energy cost for recycled liquor treatment.

Figure 18. Again, these curves reflect the incremental between wastewater treatment with and without recycling of the liquor. The requirements include time for operating and controlling the secondary treatment and thickening processes, maintaining aeration equipment and basins, and maintaining settling and pumping systems.

Figure 19 presents annual costs for performing the above functions and is based, as for direct labor costs for thermal treatment, on a unit labor cost of $7.00 per hour.

Materials and Supplies (Liquor Treatment)

The incremental cost for supplies and materials needed for operation and maintenance of the secondary process are shown in Figure 20. These costs represent the difference in expected annual expenditure for a treatment plant with and without recycle liquor. Costs are taken from B & V and are updated to March 1975. They cover materials such as paint, lubricants and replacement parts, bearings, seals, air filters, diffusers, lab supplies, manufacturer's assistance and other items normally required in a secondary treatment plant.

INDIRECT COSTS FOR TREATING ODOROUS OFF-GAS

The sources and characteristics of odorous gas and vapor streams emanating from thermal treatment processes and the methods for their control were discussed in Section VI, including incineration, adsorption, scrubbing, masking, the use of chemical additives, dilution and prevention by limiting evaporation. All of these methods have been used alone or in combination in attempts to control odors from various locations in treatment plants. The choice of method is dependent on the make-up of the odor, its strength, the environment around the plant, cost and other factors.

The methods most commonly used and most generally effective for controlling odors from thermal treatment are high temperature incineration, adsorption on activated carbon, and chemical scrubbing. Costs for these three methods are developed in this section.

Other methods such as oxidation with ozone, low temperature catalytic burning, and masking in most cases have not proven effective or reliable and are not discussed further. Inexpensive methods such as dilution or submerged discharge into various processes may or may not be applicable for particular situations and also are not considered.

The costs given in this section represent the costs necessary to treat concentrated, high-hydrocarbon gas streams coming primarily from gas separators or covered decanting tanks. Commonly, five to ten percent of the total costs for thermal treatment are represented by the requirements for odor control. Costs for treating comparable gas discharges from dewatering processes are considered common to other sludge handling systems within a plant so are not covered separately. They can be determined, however, using the information given below. Likewise, costs for ventilating, heating, and air conditioning of the thermal treatment building are not included. These

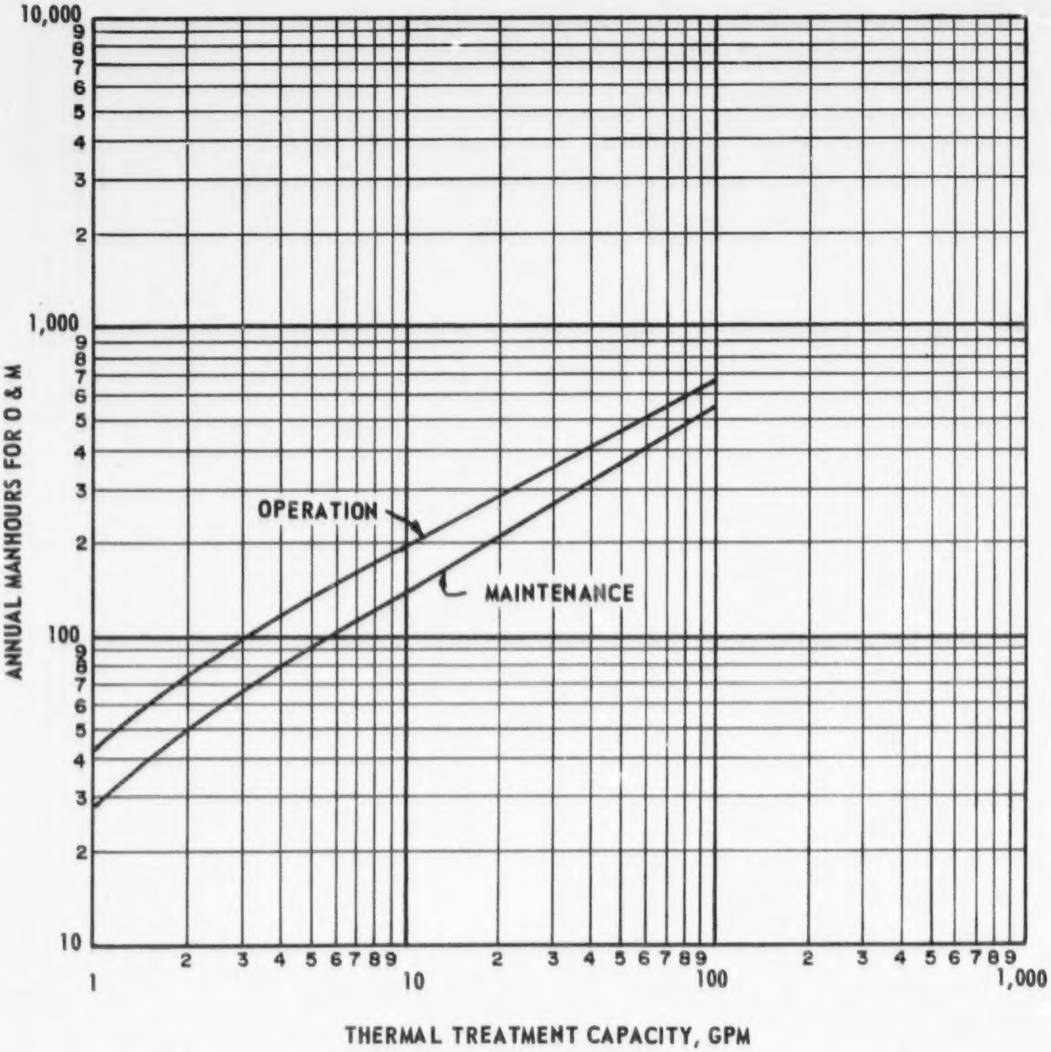


Figure 18. Incremental requirements for operation and maintenance labor for recycled liquor treatment.

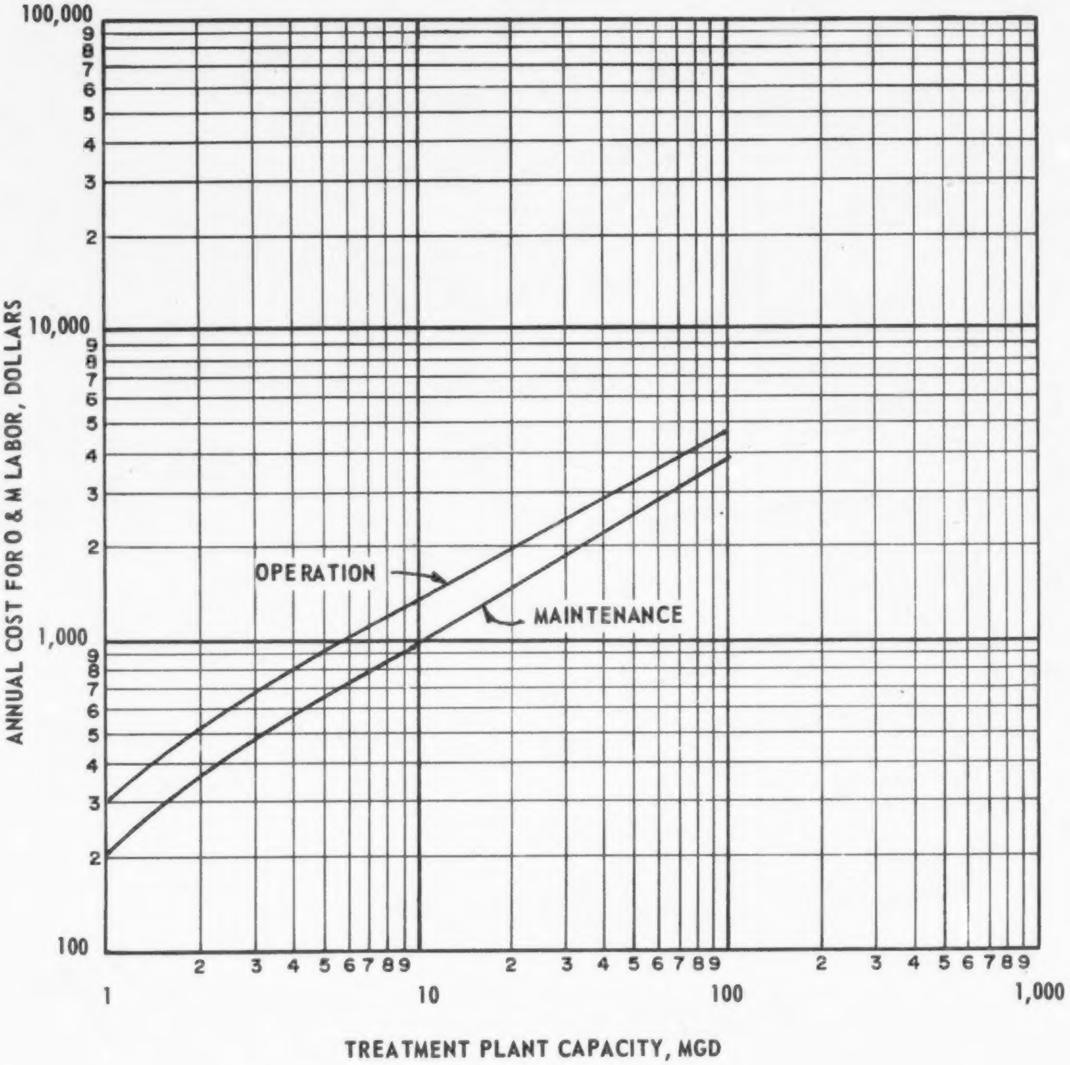


Figure 19. Incremental cost of operation and maintenance labor for recycled liquor treatment.

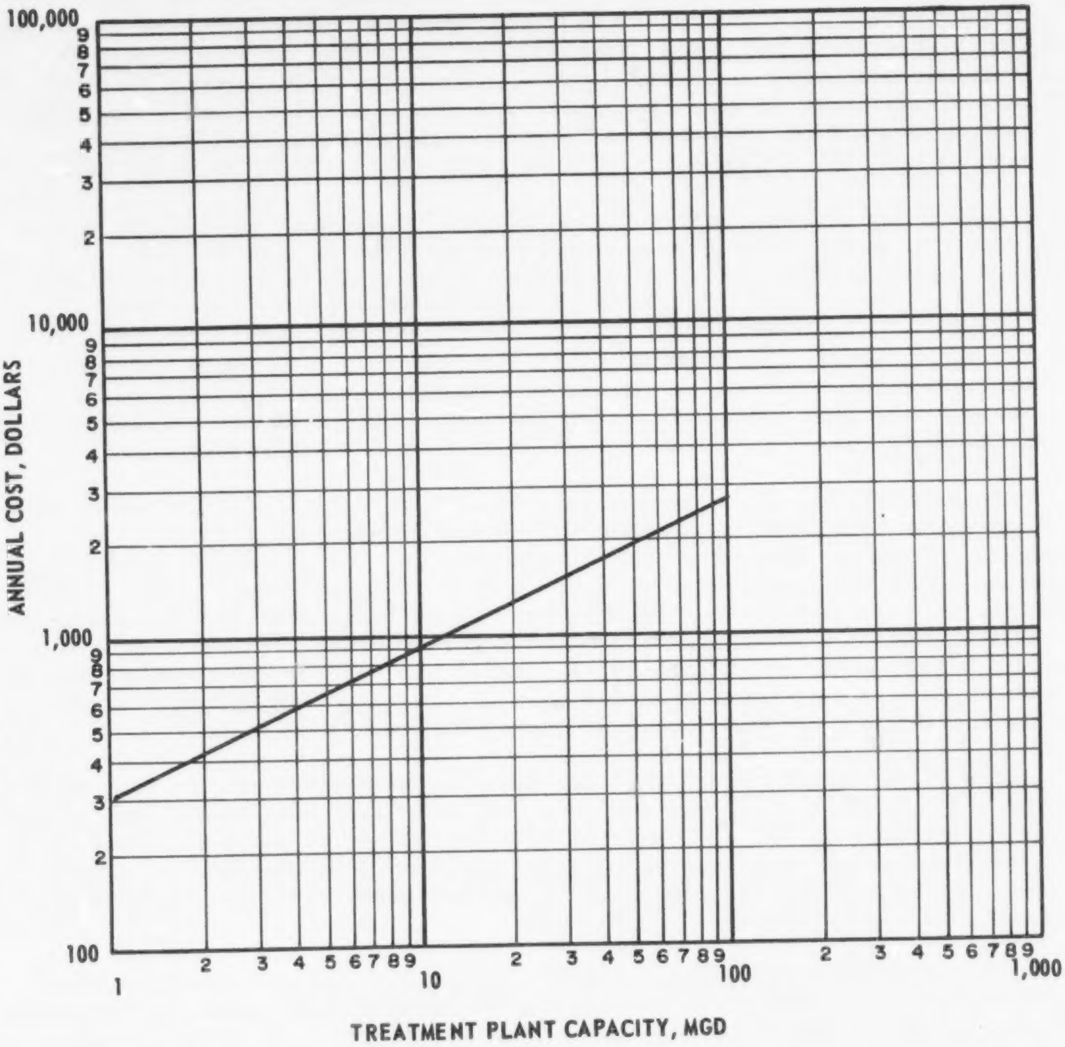


Figure 20. Incremental cost of materials and supplies for recycled liquor treatment.

costs are included in the building costs given in the section on direct costs.

The costs developed for the three methods are representative of complete odor control systems and include costs for collection of gas; ducting; fans; chemical feeding, mixing, and storage equipment; automatic control systems; disposal of removed and waste materials, and discharge of treated gas as well as for odor removal itself. Table 3 lists the requirements for the three methods based on a typical 1,000 cfm odor control system. A concentrated gas stream of 1,000 cfm corresponds to a thermal treatment plant size of 200 to 250 gpm or a sewage treatment plant size of 50 to 60 mgd.

The incineration or afterburning process considered consists of pretreatment by water scrubbing using treated effluent in a packed bed and direct flame incineration at 1,500°F with recovery of forty percent of the input heat. The carbon adsorption process includes prescrubbing with effluent, dual-bed adsorption on activated carbon, regeneration of carbon with low pressure steam, condensation of vapors, and incineration of the waste organic stream. The chemical scrubbing system utilizes three stages of scrubbing in packed beds. The first two stages use secondary effluent and a final stage uses a buffered, potassium permanganate solution.

In general, all three systems are capable of reducing the total hydrocarbon content of thermal treatment off-gases by approximately 85 to 90 percent. However, because of the difference found in sewages, sludges, reactor conditions, economies of size, etc., not all are applicable or even useable in every situation. Pilot tests or, at least detailed analyses, are recommended to determine the best method, to set design criteria, and to verify anticipated results and costs. Using the typical requirements listed in Table 3, costs are developed for each of the three control systems. These costs for the three 1,000 cfm systems are shown in Table 4.

The listed costs assume the same basis as used elsewhere in this report. Labor is charged at $7.00 per hour and fuel and electrical energy are charged respectively at $2.80 per million Btu and $0.03 per kwh. Costs for construction assume that the odor control system is constructed as a part of a complete thermal treatment system and are March, 1975 national average costs.

Figure 21 compares construction costs and odor control facility size for the three processes. In all but the smallest plants, chemical scrubbing has the lowest initial costs. Carbon, because of its more complex control system and greater amount of equipment (boiler, insulated pressure vessels, liquid burner, etc.) is the most costly in all cases. Incineration has the lowest initial cost for very small plants but increases in cost more rapidly than the other methods.

Operation and maintenance costs for the three treatment methods are shown versus size in Figure 22. Costs for incineration are dominated by the high fuel requirement which is related directly to air flow. Labor costs for incineration are quite low.

TABLE 3

UTILITY, CHEMICAL, AND LABOR REQUIREMENTS FOR ODOR CONTROL SYSTEMS

System(1)	Fuel btu/ Day	Power kwh/ Day	Effluent Water Gals./ Day	Potable Water Gals./ Day	Chemicals lbs/day	O & M Labor Hrs./ Day
Incineration	53×10^6	176	22×10^3	-	-	0.5
Carbon Adsorption	1.5×10^6	211	181×10^3	-	25(2)	1
Chemical Scrubbing	-	211	86×10^3	390	97(3)	1

(1) Based on 1,000 cfm

(2) Buffered $KMnO_4$

(3) Make-up Carbon

TABLE 4

COSTS FOR ODOR CONTROL SYSTEMS

	$/Day					Total		
System(1)	Fuel	Power	Water	Chemical	Labor	$/Day	$/Year(2)	Construction $
Incineration	148.40	5.30	-	-	3.50	157.20	52,400	88,100
Carbon Adsorption	6.40	6.30	-	25.00	7.00	44.70	14,900	182,300
Chemical Scrubbing	-	6.30	1.20	67.90	7.00	82.40	27,500	46,700

(1) Based on 1,000 cfm

(2) Based on 8,000 hrs/year operation of the thermal treatment system

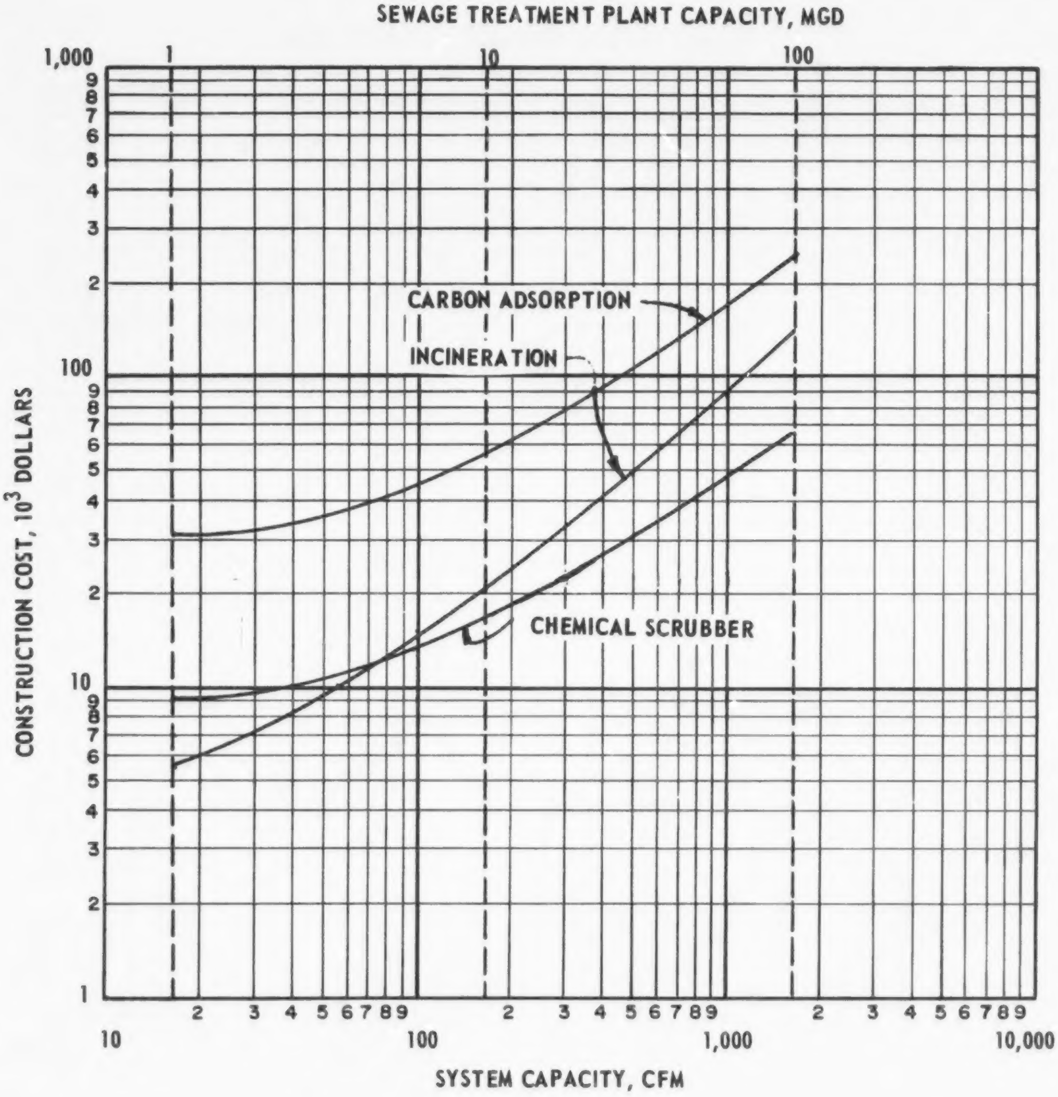


Figure 21. Construction cost for odor control systems.

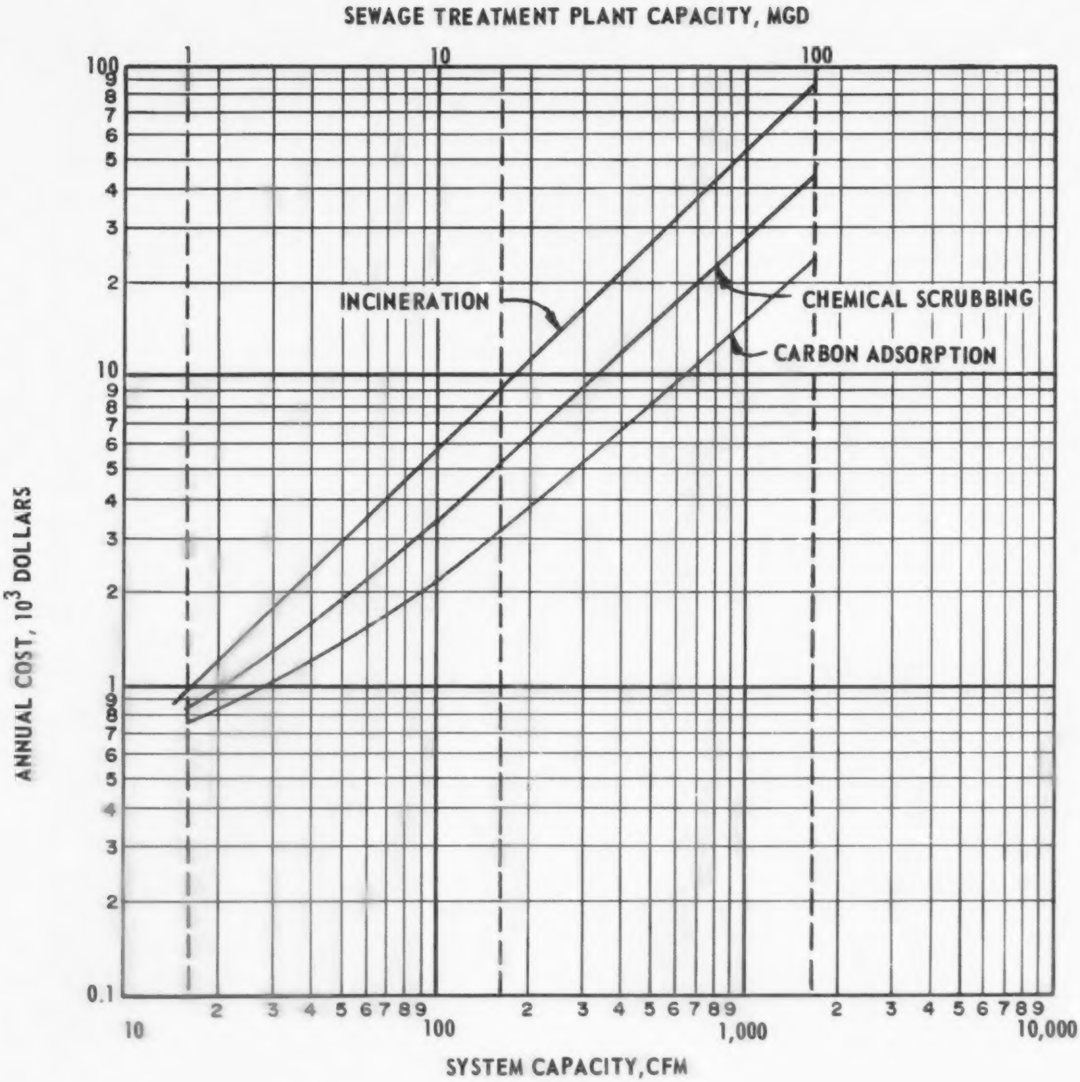


Figure 22. Operation and maintenance costs for odor control systems.

The predominant item for scrubbing is the cost of the oxidizing chemicals and for the adsorption process is the make-up carbon. The requirements for both these materials are directly proportional to the system capacity.

From the standpoint of total cost for odor control, incineration and scrubbing are the least expensive methods for use in very small plants. As size increases, however, total costs for scrubbing and adsorption become more attractive.

It must be emphasized again, that odor control systems for use in thermal treatment plants must be selected on the basis of what will adequately treat the specific off-gas involved. Only after it is determined that more than one process will perform adequately, can selection be made on the basis of cost.

SUMMARY OF DIRECT AND INDIRECT COSTS

In this section, construction costs and operation and maintenance costs for direct thermal treatment and for handling and treatment of process liquors developed earlier are combined for a typical plant and sewage. Whereas these costs were developed on the basis of the process variable most controlling of the cost -- gpm of thermal treatment capacity for direct costs and mgd of treatment plant capacity for indirect costs -- they are combined on the basis of weight of sludge to be processed.

Weight is used as the basis for general presentation because it is the unit most commonly used in the comparisons and costing of solids handling processes. For processes such as thermal treatment in which costs are largely related to liquid flow, certain obvious limitations and complexities arise in using a weight basis. In this report the complexities are handled by developing a procedure for converting and then developing costs for one representative case. The procedure involves first determining the characteristics of the raw sewage to be treated, selecting the liquid treatment process to be used, and making process design calculations which normally would be made during the preliminary design of a sewage treatment plant. The primary parameters to be determined are the weight of sludge to be handled, the concentration of the sludge to be treated, and the characteristics of the recycled liquor streams. A mass balance similar to that shown earlier is helpful in determining the effect of recycle on the total amount of sludge to be processed. For quick estimates, the various parameters can be estimated with reasonable accuracy. From these calculations the flow of sludge can be determined.

Figures 7 through 14 can then be used to determine the direct costs and requirements and, knowing the raw sewage flow, the costs and requirements for treating the recycled liquor can be determined from Figures 15 through 20. Although costs for odor control are included in Figure 8, if desired, five percent can be subtracted from the indicated cost, and odor control costs more accurately determined from Figure 21 and added to the remainder.

An example of the calculation required to determine construction and operation and maintenance costs for a typical thermal treatment facility is given in Table 5. The table lists the basic assumptions made, lists the steps to follow, and the curves to use. The example uses those curves giving operation and maintenance requirements directly in dollars per year. However, if different unit costs for labor and energy are applicable, the basic curves can be used in an identical procedure to get annual requirements in man hours, Btu's and kwh's. These requirements can then be multiplied by the appropriate unit costs to arrive at total cost.

Total costs for a typical thermal treatment system are developed and shown in Tables 6 and 7. The factors and parameters used to develop the tables have been discussed above under "Indirect Costs" and are for a primary/secondary treatment plant using the activated sludge process, thickening, and vacuum filtration. Raw sewage to the plant has BOD and suspended solids concentration of 250 mg/l each. Prior to thermal treatment, sludge is thickened to 4 1/2 percent solids and after thermal treatment, sludge is dewatered to 40 percent solids. The analysis shows that approximately 1.1 tons of solids per million gallons are produced from the raw sewage and recycled liquor, and that 4 gpm per million gallons flows to the thermal treatment facility. The thermal plant is sized for 8,000 hours per year of operation (a down time of approximately 9 percent). Construction costs are amortized over twenty years at seven percent.

Table 6 shows the combined construction cost for plants ranging in size from one to 100 tons per day. These costs are exclusive of engineering, administrative and financing costs. Apparent from the table is that, because of the very high unit construction cost for small thermal treatment plants, construction costs for liquor treatment is only a small percentage of the total cost. The percentage of construction costs related to liquor treatment increases rapidly as the plant size increases and reached 15 percent at 100 tons per day. For the given conditions, total construction cost varies from $393,000 for a one ton per day plant to $5,003,000 for a 100 ton per day plant. These costs result in amortized construction costs of approximately $100 per ton for a one ton/day plant to $13 per ton for a 100 ton per day plant.

The operation and maintenance costs for thermal treatment plants follow the same pattern as construction costs, starting quite high -- $155 per ton for a one ton per day plant, and dropping rapidly to less than $20 per ton for a 100 ton per day plant. The ratio between direct and indirect costs follows almost the same pattern found for construction costs.

Analysis of the various elements of operation and maintenance costs shows that indirect costs result primarily from the energy required for aeration. Direct costs are dominated by the high requirements for operating labor. The cost of direct operating labor in a one ton per day plant is approximately 60 percent of the total O & M cost. This percentage drops to about 26 percent for a 100 ton per day plant but the figure is still quite significant.

Since operating labor is such a major factor in small plants and construction costs do not decrease in proportion to decreases in thermal system capacity, it is apparent that a size is reached below which continuous

TABLE 5

EXAMPLE CALCULATION OF DIRECT & INDIRECT COSTS

A. Basis

1. Q = 10 mgd
2. Solids to be treated = 1.1 tons/mgd
3. Solids concentration to thermal treatment = 4.5%
4. Annual hours of operation = 8,000 (Downtime = 9%)
5. Thermal treatment process = low oxidation

B. General

1. Weight of sludge to be treated
   10 mgd x 1.1 ton/mgd = 11 tons/day
2. Size of thermal treatment unit
   11 tons/day @ 4 1/2% solids = 40 gpm
   40 gpm x (8760 hrs/yr ÷ 8,000 hrs/yr) = 44 gpm

C. Capital Costs

Direct Cost From Figure 8, Curve B	$ 890,000
Indirect Cost From Figure 15	120,000
Construction Cost	$1,010,000
Engineering	100,000
Legal and Administrative	10,000
Interest during Construction	80,000
Total Capital Cost	$1,200,000

D. Operation and Maintenance Cost

Direct Operations Labor (Figure 13)	$ 55,900
Direct Maintenance Labor (Figure 13)	12,300
Indirect Operations Labor (Figure 19)	1,300
Indirect Maintenance Labor (Figure 19)	900
Direct Fuel (Figure 11)	30,000
Direct Power (Figure 11)	19,000
Indirect Power (Figure 7)	10,400
Direct Materials (Figure 14, Cuve B)	12,300
Indirect Materials (Figure 20)	900
Annual O & M Cost	$ 143,000

E. Total Annual Cost

Amortized Capital Cost @ 7% - 20 years $1,200,000 x 0.09439 =	$ 113,300
Annual O & M Cost	143,000
Total	$ 256,300

$$\text{Cost per million gal.} = \frac{\$256{,}300}{365 \times 10} = \$70$$

$$\text{Cost per ton of solids} = \frac{\$256{,}300}{365 \times 11} = \$68$$

TABLE 6

Direct and Indirect Construction Cost for Thermal Treatment (Solids Basis)

Sludge[1]		Tons/day				
		1	5	10	50	100
Direct costs	(10^3 Dollars)	377	595	830	2359	4239
Indirect costs	(10^3 Dollars)	16	62	113	394	764
Total costs	(10^3 Dollars)	393	657	943	2713	5003
Indirect ÷ Total	%	4	9½	12	13	15
Amortized Cost[2]						
Cost/yr	(10^3 Dollars)	37.1	62.0	89.0	256.1	472.2
Cost/ton	(Dollars)	101.64	33.97	24.38	14.03	12.94

(1) Basis
- a) 1.1 tons solids per mgd-Includes recycle
- b) 4 gpm to thermal treatment per mgd @ 4½ solids
- c) 8000 hrs/yr operating time

TABLE 7

Direct and Indirect Operation and Maintenance
Cost for Thermal Treatment (Solids Basis)

Sludge[1]	Tons/day				
	1	5	10	50	100
Direct costs (10^3 dollars/yr)					
Fuel	$2.6	$13.1	$26.5	$131.2	$265.0
Electrical Energy	3.7	10.0	16.7	59.5	104.3
Operating Labor	33.3	42.7	52.6	108.7	158.5
Maintenance Labor	8.3	10.0	11.8	22.0	32.0
Materials & Supplies	6.9	9.0	11.2	27.1	45.5
Total	54.8	84.8	118.7	348.5	605.3
Indirect costs (10^3 dollars/yr)					
Electrical Energy	1.0	4.7	9.7	47.4	94.0
Operating Labor	0.3	0.8	1.3	3.0	4.5
Maintenance Labor	0.2	0.6	0.9	2.4	3.7
Materials & Supplies	0.3	0.6	0.9	1.8	2.5
Total	1.8	6.7	12.8	54.6	104.7
Total-Direct and Indirect (10^3 dollars/yr)	56.6	91.5	131.5	403.1	710.0
Indirect ÷ Total (%)	3	7	9½	13½	14½
Cost/Ton (Dollars)	155.07	50.13	36.02	22.09	19.45

(1) Basis--see Table 5.

operation is no longer desirable and that savings would be achieved by finding the optimum relationship between hours of operation, design capacity, and sludge storage.

Table 8 summarizes the direct, indirect, and total costs for construction and for operation and maintenance for several sludge capacities.

The total costs for thermal treatment - direct and indirect - range from $257 per ton to $32 per ton for sludge capacities of one to 100 tons per day. It must be kept in mind, however, that the costs presented above are for one representative but particular set of conditions. One additional figure (Figure 23) is presented to serve as a quick visual reference to the costs for thermal treatment. It is based on the same set of conditions used above, and shows total construction cost, amortized construction cost, annual O & M cost, and total annual cost for a range of plant sizes. Plant sizes are shown for both solids loading to the thermal treatment system over a range of one to 100 tons per day and sewage treatment plant flow over a range one to 100 mgd.

TABLE 8

Summary of Direct and Indirect Cost for
Thermal Treatment (Solids Basis)

Sludge[1]	Construction Cost[2] [3]			O & M Cost			
Tons/day	Direct	Indirect	Total	Direct	Indirect	Total	Total Cost
1	97.53	4.11	101.64	150.14	4.93	155.07	256.71
5	30.79	3.18	33.97	46.46	3.67	50.13	84.10
10	21.45	2.93	24.38	32.52	3.50	36.02	60.40
50	12.20	1.83	14.03	19.10	2.99	22.09	36.12
100	10.96	1.98	12.94	16.58	2.87	19.45	32.29

(1) Basis--see Table 5.
(2) Amortized 20 years-7%.
(3) All costs in dollars/ton.

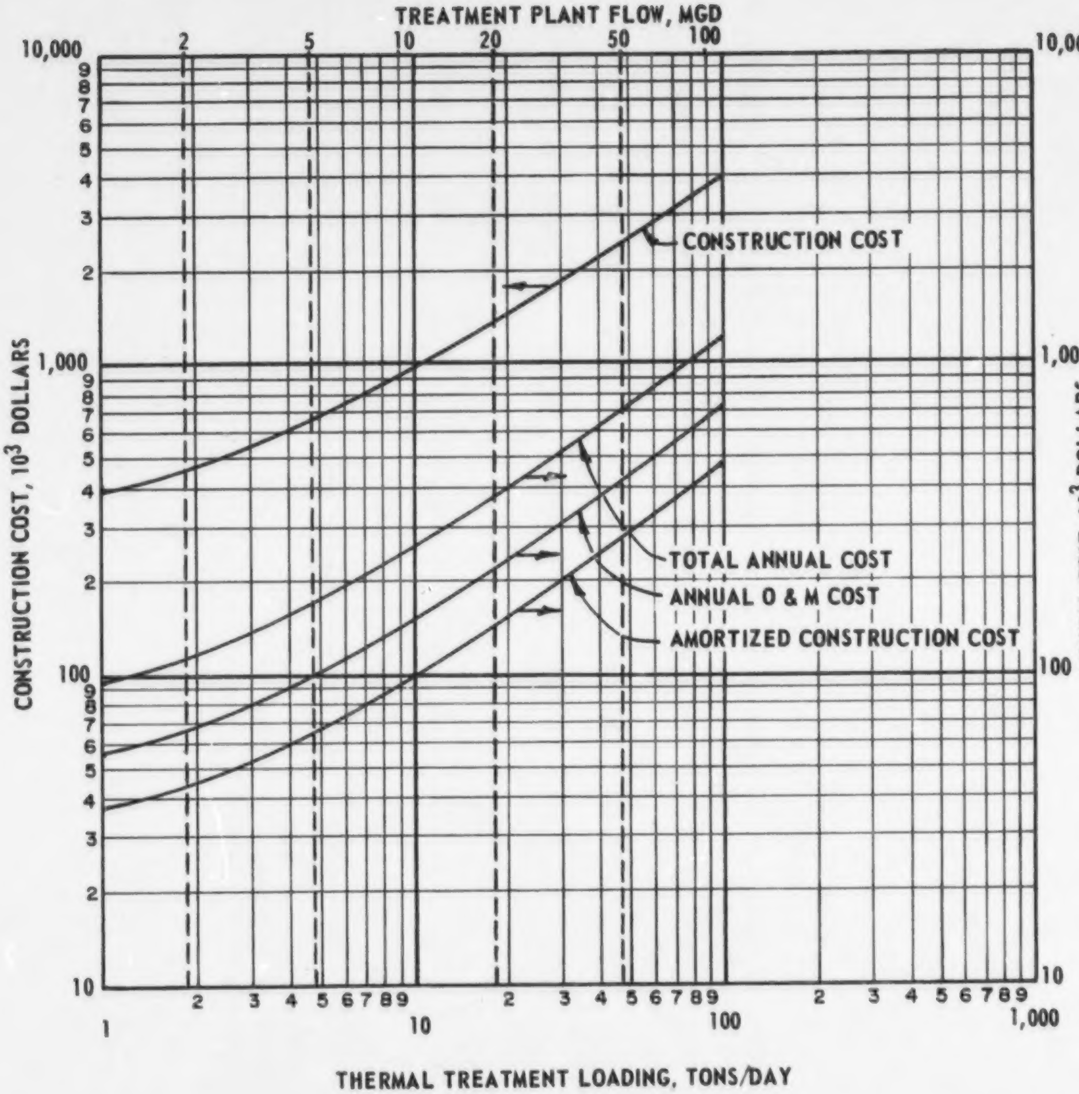


Figure 23. Direct and indirect costs for thermal treatment.

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APPENDIX A

JAPANESE EXPERIENCE WITH HEAT TREATMENT

GENERAL

As reported in EPA 670-9-75-005 (May 1975), Proceedings of the Third US-Japan Conference on Sewage Treatment Technology, a study was conducted on heat treating of sludges to improve dewaterability. The study was undertaken by the Japanese Government's Ministry of Construction and was under the direction of the Committee for Investigation into Sludge Handling and Disposal of the Japan Society of Civil Engineers.

The purposes of the study were to find and enumerate the benefits of and problems with the use of heat treatment processes and to determine solutions to the problems. Principal elements of the study included:

1. literature review of heat treatment experiences in Europe;
2. laboratory work to determine the effects and problems which could be expected in Japan;
3. assessment of heat treatment and its problems and economics based on studies of full-scale, operating plants;
4. characterization of supernatant quality and development of supernatant treatment techniques;
5. characterization of odors and their sources and evaluation of odor control methods; and
6. investigation of process equipment from the standpoints of estimating operational and maintenance requirements, selecting materials for construction, and determining system reliability.

To implement the full-scale phases of the study, heat treatment facilities were constructed at three sites. These are referred to as: Sakai (Semboku Plant), Fujisawa (Nambu Plant) and Sapporo (Toyohiragawa Plant).

LABORATORY STUDIES

Laboratory work performed using sludges from the Nambu Plant, the Semboku Plant the Toba Plant at Kyoto gave the results below.

1. At temperatures above 180°C (356°F) both excess activated sludge (WAS) and primary sludge (PS) could be filtered readily. As the temperature was increased, the moisture content of the filter cake decreased.

2. Residence time in the reactor was not a significant factor in determining cake moisture. It was noted that for a constant time and temperature the cake from primary sludge would have a lower moisture content than that from WAS.

3. High treating temperatures and longer residence times resulted in higher filtration rates.

4. Specific resistance of the sludge was affected mainly by the organic content up to temperatures of about 180°C (356°F). Above 190°C (374°F), however, the specific resistance dropped sharply.

5. Biochemical oxygen demand, chemical oxygen demand, ammonia and color in the supernatant from both WAS and PS increased sharply as temperatures were increased about 180°C (356°F).

6. As the organic content of sludge increased, its ability to be solubilized also increased. More waste activated sludge was solubilized for a fixed set of reactor conditions than was PS or a mixture of PS and WAS.

7. Baking of solids in heat exchangers became excessive at temperatures above 200°C (392°F).

8. Scorching of heat exchange tubing increased as the organic content of the sludge increased.

It was concluded from the laboratory studies that heat treatment as a pretreatment for mechanical dewatering was effective at temperatures as low as 180°C (356°F) and with residence times of between 30 to 60 minutes as long as the organic content of the sludge was relatively constant and between 50 and 60 percent. If the organic content exceeded 60 percent or if it was variable, an increase in temperature to 190°C (374°F) or even to 200°C (392°F) for 30 to 60 minutes would be desirable.

FULL-SCALE STUDIES

Design data for the three previously mentioned plants where the full-scale heat treatment studies were carried out are summarized in Table A-1. A flow sheet of the typical heat treatment plant is shown in Figure A-1. As can be seen from the flow sheet, solids were to be concentrated in a gravity thickener prior to heat treatment. This thickening process was expected to raise the concentration of solids from a level of 1 to 2 percent in the raw sludge to a level of 4 to 5 percent in the reactor feed. After heat treatment and thickening, a solids content of 50 to 60 percent was anticipated. Design temperatures for the reactors were set at 200°C (392°F), and residence times varying between 30 and 120 minutes were selected.

TABLE A-1

DESIGN DATA FOR HEAT TREATMENT FACILITIES IN PROJECTED SITES

Items	Toyohiragawa, Sapporo	Nambu, Fujisawa	Semboku, Sakai
Date of operation	October, 1970	August, 1964	March, 1969
(1) Sewer system	Combined sewer (domestic sewage only)	Combined sewer (partially combined & partly incl. industrial effluents)	Separate sewer. (domestic sewage)
(2) Description			
Served population	200,000	228,000	221,000
Volume of sewage flow, average	16.9 mgd	20.3 mgd	22.7 mgd
(3) Sewage treatment process	Activated sludge (step aeration possible)	Activated sludge (step aeration system)	Activated sludge (step aeration system)
(4) Heat treatment system	Porteous system	Von-Roll system	Porteous system
(5) Design data			
Quality of influent	BOD 200 ppm SS 250 ppm	BOD 200 ppm SS 250 ppm	BOD 200 ppm SS 300 ppm
Total solids of raw sludge	22.2 t/day	6.4 t/day	8.6 t/day
Moisture content of raw sludge	99%	98%	98%
Volume of raw sludge	620,000 gpd	76,000 gpd	104,000 gpd
Moisture content of thickened sludge	95%	96%	96%
Volume of thickened sludge	107,000 gpd (74 gpm)	38,000 gpd (26 gpm)	52,000 gpd (36 gpm)
Moisture content of heated sludge	90%	92%	90%
Total solids of heated sludge	17.7 t/day	5.1 t/day	6.4 t/day
Weight of heated sludge	177 t/day	63 t/day	60 t/day
Moisture content of cake	47%	40%	50%
Cake weight	33 t/day	8.5 t/day	11 t/day
(6) Heat treatment facilities and operating conditions			
Raw sludge temperature	10°C (50°F)	20°C (68°F)	15°C (59°F)
Outlet temperature of heat exchanger	165°C (329°F)	160°C (320°F)	160°C (370°F) (from reactor)
Heat treating temperature in reactor	200°C (392°F)	200°C (392°F)	200°C (392°F)
Outlet temperature of heat exchanger	55.3°C (132°F)	62°C (144°F)	60°C (140°F) (to reactor)
Sludge cooler outlet temperature	(excl. from 1st stage)	25°C (77°F)	Influent temp. 15°C (59°F)
Conditioning time in reactor	45 min.	60-120 min.	30-60 min.

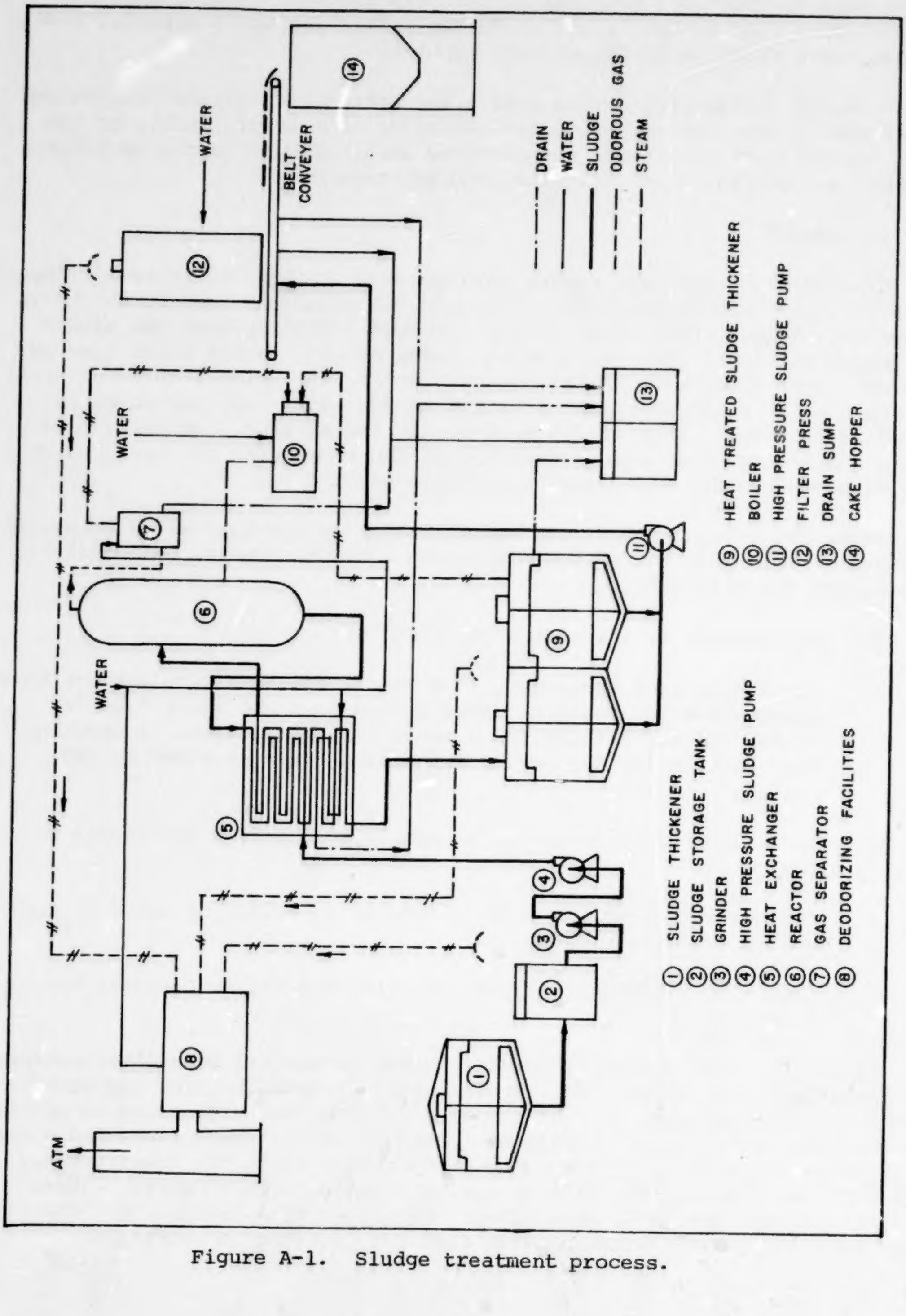
ATM
WATER
WATER
WATER
BELT CONVEYER
① SLUDGE THICKENER
② SLUDGE STORAGE TANK
③ GRINDER
④ HIGH PRESSURE SLUDGE PUMP
⑤ HEAT EXCHANGER
⑥ REACTOR
⑦ GAS SEPARATOR
⑧ DEODORIZING FACILITIES
⑨ HEAT TREATED SLUDGE THICKENER
⑩ BOILER
⑪ HIGH PRESSURE SLUDGE PUMP
⑫ FILTER PRESS
⑬ DRAIN SUMP
⑭ CAKE HOPPER
DRAIN
WATER
SLUDGE
ODOROUS GAS
STEAM

Figure A-1. Sludge treatment process.

Results from one year of operation are shown in Table A-2. A comparison of the data in Table A-2 with the design criteria and expected treatment results shows that in nearly all cases the thickening and dewatering levels achieved were equal to or higher than expected.

Problems encountered during full-scale operation included erosion and deposition in heat exchangers, odors emanating from several parts of the plant, disposal of the highly concentrated supernatant from the dewatering process, and general plant operation and maintenance.

HEAT EXCHANGERS

Problems with heat exchangers involved both erosion of tubes and deposition of solids within the tubes. The type of exchanger used in all three plants was the concentric tube design operated initially with raw sludge flowing in the inner tube and treated sludge flowing in the outer tube or annulus. Some tubes from the exchangers in all three plants suffered from erosion and corrosion at rates up to 0.7 mm per year - and had to be replaced or repaired. Most of the wear was in the annulus. Deposition of solids and baking of organic material onto the tubes with a corresponding loss of heat transfer efficiency was also a problem.

After the initial operation, modifications to the heat exchange system were made. This work was followed by three additional months of operation to evaluate the modification.

The improvements to the system consisted of:

1. converting heat exchangers from the sludge-to-sludge pattern to a sludge-to-water pattern. This method used the inner tube for sludge and the annulus for a water exchange medium. A smoother flow pattern for the heat treated sludge was provided by the change;

2. installing a cushion or surge tank upstream from the sludge discharge valve;

3. precooling the heat treated sludge by injection of water at the outlet from the reactor; and

4. employing a hydraulically-driven cleaning bullet to clean the inner tubes.

After the three months of operation, the exchangers were disassembled and inspected. The inspection revealed that the modifications had been effective in eliminating most of the earlier problems. There was no abrasion nor corrosion noted, high temperature portions of the inner tubes had a hard, black organic scorch up to 2 to 3 mm in thickness while the lower temperature portions were covered with up to 1mm of soft organic layers. These depositions were removable with use of the bullet cleaning method. The outer tube was covered with an oxide film but was in good condition.

TABLE A-2

OPERATIONAL DATA OF HEAT TREATMENT PLANTS (FROM APRIL, 1972 TO MARCH, 1973)

Item	Toyohiragawa, Sapporo			Nambu, Fujisawa			Semboku, Sakai		
	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum
Average sludge solid, tons/month		618			123			118	
Monthly average moisture content,		95.3			96.7			96.1	
Heat treatment capacity, gpm		110			29			45	
Heat treating temperature	200°C (392°F)	198°C (388°F)	195°C (383°F)	201°C (394°F)	195°C (383°F)	180°C (356°F)	200°C (392°F)	194°C (381°F)	190°C (374°F)
Heating time, min.	34	30	27	120	120	60	April - August 29.4 September - March 47.9	47.5 45.5	26.3 42.9
Moisture content of heat treated sludge, %	86.5	84.3	81.4	85.1	78.1	71.3	94.9	87.8	83
Moisture content of sludge cake, %	37.2	36.1	35.1	46.3	37.2	33.1	54.6	47.8	40.6
Properties of supernatant:									
Temperature	53°C (127°F)	43.3°C (110°F)	28°C (82°F)	36.1°C (97°F)	29.1°C (84°F)	22.1°C (72°F)	29.0°C (84°F)	24.8°C (77°F)	19.0°C (66°F)
pH	5.7	5.5	5.3	5.8	5.7	5.4	5.8	5.2	4.6
Total solids, mg/l	5,950	5,232	4,838	8,100	5,978	4,160	9,899	7,191	4,362
Dissolved solids, mg/l	4,040	3,908	3,690	7,900	5,575	3,690	9,252	6,644	3,946
SS, mg/l	2,260	1,325	978	650	403	200	1,008	547	118
COD ($KMnO_4$), mg/l	1,800	1,590	1,280	4,700	2,975	2,050	3,520	2,615	1,600
BOD_5, mg/l	6,000	5,155	3,520	6,100	4,413	3,400	7,660	5,847	4,204
T-N, mg/l				1,100	664	410	1,349	704	258
Properties of effluent:									
BOD_5, mg/l	17.3	11.4	5.2	25.0	14.4	5.5	18.2	12.8	7.9
SS, mg/l	41.4	25.9	18.3	29.0	14.6	7.0	34.0	19.5	9.0
Supernatant treatment	Supernatant diluted 300%, aerated 24 hours and then fed back to pre-aeration tank			Directly discharged to raw sewage			Directly discharged to raw sewage		

CORROSION

Experiments to determine the corrosive effects of the reactor environment to various steels were run at all three plants. At two plants test pieces of mild boiler steel, SB42 JIS G3103 (ASTM A285 grade C), were set in operating reactors for twelve months. Measurement and analysis showed that the rate of corrosion was very slow and was uniform over the entire surfaces of the test pieces. It was found that the layer of Fe_3O_4 was firmly attached to the metal and inhibited further corrosion. The mild steel was judged suitable for reactor construction.

Prestressed test pieces of SUS 32 and SUS 27 (AISI types 316 and 304) stainless steels were subjected to conditions similar to those for the mild steel. After nine months in the reactor, the SUS 32 steel showed no problematic corrosion such as stress corrosion, cracking, pitting or intergranular corrosion and also was judged suitable for reactor construction. At the same time, SUS 27 steel was judged unfit because of the excessive stress corrosion noted.

ODORS

Strong odors were noted emanating from the reactors, thickeners, filters and storage hoppers. Odorous gases from gas separators and thickeners were burned in the boilers or in incinerators. Foul air from sludge processing areas was also burned or, in some cases, vented or scrubbed and sprayed with deodorant.

To increase the efficiency of odor removal, studies were conducted using catalytic combustion, oxidation with ozone and water scrubbing. It was thought that if catalytic combustion at 200°C (392°F), the temperature of the available steam source, was effective in removing odors, operating cost would be reduced.

Odorous gases were treated in a column packed with catalyst (type not given) and burned 200 to 300°C (392 to 572°F). Analyses of the treated gases showed the removals listed:

Chemical	Temperature	Removal
H_2S	250 to 300°C (482 to 572°F)	Complete
NH_3	200 to 300°C (392 to 572°F)	Complete
CO	200 to 300°C (392 to 572°F)	80%
Hydrocarbons	300°C (572°F)	50%

Further testing with a gas chromatograph showed that the peak of the hydrocarbon spectrum shifted toward smaller molecular weight compounds during treatment. This testing also showed that amines and mercaptans were substantially to completely removed during catalytic treatment. The method appeared to be quite effective for odor control, however, no data were given on its costs. Odor causing compounds were identified as ammonia, hydrogen sulfide, ethyl and diethyl amines, and ethyl and propyl mercaptans.

Oxidation with ozone was studied as a method for treating large volumes of diluted, odorous gases from space-ventilating systems. When ozone was applied at a rate of several tenths of a part per million to dilute gases in a humidified reactor, no sensible odor was found. Analyses showed, however, that while offensive odors and the levels of amines and mercaptans were substantially reduced, hydrocarbon dissociation was only 10 to 15 percent.

As an alternate to oxidation with ozone, scrubbing with water was also studied. Secondary effluent was used as the liquid in a scrubbing tower. It was found that, at a water to air ratio of one to one by weight, the treated gas had almost no sensible odor.

TREATMENT OF SUPERNATANT

As previously mentioned, the quality of the supernatant is given in Table A-2. The volume of supernatant averaged about 0.5 percent of plant influent and was dependent upon time and temperature in the reactor and upon the ability to thicken the raw and heat-treated sludges. A summary of supernatant characteristics is given below:

pH	5 - 6
COD ($KMnO_4$)	1300 - 5000 mg/l
BOD	3500 - 8000 mg/l
Total Solids	4200 - 10,000 mg/l
Total Nitrogen	300 - 1400 mg/l

If returned to the head end of the plant and mixed with influent for retreatment, the supernatant added 10 to 20 percent to the BOD loading on the plant.

Studies were made of several methods for treating and disposing of supernatant. The general methods included returning the supernatant directly to plant aeration tanks and diluting and preaerating the supernatant prior to returning it to the plant. Experiments were conducted with (1) returning supernatant to the conventional activated sludge process, (2) returning supernatant to a step aeration process, (3) direct aeration of dilutes and undiluted supernatant in an extended aeration process, and (4) aerobically digesting the supernatant.

Conventional Activated Sludge

Returning supernatant directly to conventional activated sludge plants resulted in the development of some odor and a dark brown color in the effluent. However, diluting the supernatant three hundred percent with plant effluent and aerating it 24 hours prior to returning it to the plant produced what was described as a satisfactorily processed effluent.

A pilot study in which 1 to 2 percent supernatant was returned to the conventional activated sludge process was run. Loadings were as shown below:

BOD Load	lb/lb MLSS/day	lb/1000 cf/day
Control	0.08 - 0.18	18 - 29
Case 1 (1%)	0.13 - 0.28	29 - 42
Case 3 (2%)	0.23	41

The results of this study were that: (1) for a one percent supernatant return and a five hour aeration time, no significant decrease in treatment efficiency from the 95 percent found for the control case was noted, (2) COD remaining for cases 1 and 2 was higher than for the control case, but removal was still greater than 80 percent, (3) effluent for those cases involving supernatant had a yellowish brown hue, (4) dissolved nitrogen in the effluent from cases 1 and 2 was 1 to 2 mg/l higher than in the control effluent, (5) because of readsorption of metals into the activated sludge, metal concentrations in the effluent from all cases was nearly constant, (6) the growth rate of cells in cases 1 and 2 was 1.5 to 2 times as great as in the control case, and (7) at one percent supernatant, sludge settling characteristics were not affected, however, in case 2 some degradation of settleability was noted. The conclusion drawn from the above was that if one percent or less supernatant is returned to the conventional activated sludge process, little effect will be noted except that the effluent will have slightly more color and a 1 to 2 mg/l higher nitrogen content.

Step Aeration

Because it was anticipated that the high BOD waste could be effectively treated by cells in their log growth phase occurring in the step aeration process, this process was studied at full-scale. Supernatant at the rate of 0.52 to 0.72 percent of the plant influent flow and 30 percent of the return sludge were treated in the first pass of a six-pass aeration basin. At those supernatant flows, 24 hours of aeration were provided in this first pass. The remainder of the return sludge and one-fifth of the primary effluent was added equally to the remaining passes. Operating results from this process showed that settling characteristics of the mixed liquor were degraded slightly; the BOD, COD (Cr), NH_3-N and suspended solids of the final effluent were 5.7 to 11 mg/l, 28.3 mg/l, 10 to 15 mg/l and less than 10 mg/l respectively. The effluent was clear and almost colorless. Odor from the aeration tank was slight and no bubbling was noted in the supernatant aeration pass.

Before changing from the conventional activated sludge process with supernatant added to the step aeration process, the effluent BOD had been as high as 20 mg/l and had a light yellow color.

Extended Aeration

Pilot studies were conducted using the extended aeration process to treat diluted and undiluted supernatant. At the Semboku Plant 59 to 66 percent of BOD was removed after 18 hours of aeration. Considerable foaming was noted during this operation.

At the Toyohiragawa Plant similar studies with both diluted and undiluted supernatant were conducted. With undiluted supernatant, foaming, as with operations at the Semboku Plant, was noted and after four days of aeration the BOD removal was only 47 percent.

Studies using supernatant dilutes 300 percent gave BOD removals of 84 percent and COD ($KMnO_4$) removals of 28 percent after 32.2 hours of aeration. An additional 24 hours of aeration increased the BOD removal to approximately 90 percent.

Aerobic Digestion

Experiments using a laboratory-scale aerobic digestor were conducted at the Nambu Plant. From this, it was concluded that a digestion time of at least 20 days was required. Using a BOD to MLSS loading of 0.1 per day, 95 percent removal of BOD was obtained. Nitrogen removal increased with digestion time, going from 16 percent in 20 days to 56 percent in 60 days. Also, color was reduced slightly with time but the dark brown color persisted throughout the testing.

HEAVY METALS

Studies were conducted at two plants to determine the fate of heavy metals found in the sludges. The ratio of heavy metals found in the supernatant to those found in the raw sludge, called the dissolving ratio, were as follows:

	Ratio (percent)	
Metal	Nambu Plant	Toyohiragawa Plant
Iron	4.19 - 5.14	8.0
Chromium	0.51 - 3.41	---
Arsenic	4.19	---
Copper	0.05 - 4.19	---
Cadmium	0.7 - 9.61	---
Zinc	0.42 - 1.28	1.3
Lead	2.67 - 3.70	0.8

These studies indicated that over 90 percent of the heavy metals remained in the sludge during heat treatment and dewatering. The maximum increase in metal concentrations in the plant effluent due to recycling of supernatant were found to be 0.6 mg/l for iron and approximately 10^{-4} mg/l for Cr, Cd and Pb.

COSTS

To help evaluate possible economic advantages of heat treatment, cost comparisons were made between heat treatment followed by dewatering and anaerobic digestion followed by chemical treatment and dewatering. Table A-3 shows a comparison of the capital costs for each system. As indicated in the table, costs for heat treatment compare favorably with those for digestion - chemical treatment both for treatment preceeding dewatering and treatment through dewatering preceeding incineration. With the exception of the Toyohiragawa Plant, costs for both processes (within the expected accuracy of the estimates) are about the same.

TABLE A-3

COMPARISON OF CAPITAL COSTS PER DRY TON OF SOLIDS BETWEEN HEAT TREATING SYSTEM AND DIGESTION-DEWATERING SYSTEM (1975 DOLLARS)

Plant	Sludge solids (dry tons)/day	Heat treatment system		Digestion-chemical coagulation-vacuum filtration	
		up to dewatering ($/ton)	up to incineration, ($/ton)	up to dewatering ($/ton)	up to incineration, ($/ton)
Toyohiragawa	44.3	72,200	97,500	101,873	131,995
Nambu	19.0	140,100	---	59,400	76,148
Semboku	25.8	140,200	155,300	77,027	97,402

Similarly, as shown by Table A-4, operating costs are also comparable for the two processes. The apparent slight advantage indicated for heat treatment may be offset by the addition of costs for more sophisticated removal systems and for needed treatment of supernatant.

CONCLUSIONS AND RECOMMENDATIONS

At the completion of the three year study, the Committee reached several conclusions. Notably among them was that heat treatment is still in the development stage and consequently still has various problems which must be solved.

Other conclusions were:

1. The dewaterability of heat treated sludge is excellent and the dewatered cake burns readily without the need for supplementary fuel.
2. Heat treatment equipment if properly designed from the standpoints of preventing corrosion and ease of maintenance and cleaning will pose little problem in itself.
3. There are sufficient differences between plants and sludges to warrant complete studies including pilot analyses before selecting or designing heat treatment processes for any plant.
4. Further study is needed in the areas of odor control and treatment of supernatant.

The Committee recommended that heat treatment systems be optimized as a part of the entire treatment process and that the reactor residence time and temperature, consistent with adequate dewaterability, should be as low as possible. Further, where incineration is to follow dewatering, the use of heat-recovery boilers and the burning of various malodorous off-gases was suggested. The Committee's also recommended more standardization in unitization of equipment.

TABLE A-4

COMPARISON OF UPKEEP COSTS AND DEPRECIATION COSTS FOR HEAT TREATING AND DIGESTION-DEWATERING SYSTEMS (DOLLARS PER DRY TON)

	Heat treating system						Digestion-dewatering system					
	Up to dewatering			Up to incineration			Up to dewatering			Up to incineration		
Plant	Upkeep	Depr.	Total	Upkeep	Depr.	Total	Upkeep	Depr.	Total	Upkeep	Depr.	Total
Toyohiragawa	19.80	10.70	30.50	21.00	14.60	35.60	20.70	12.00	32.70	26.60	18.00	44.70
Nambu	33.50	19.60	53.10	---	---	---	31.40	16.50	47.90	37.20	24.50	61.70
Semboku	---	---	---	20.25	22.50	42.75	27.00	15.00	42.00	33.00	23.00	56.00

APPENDIX B

List of Metric Conversions

English Unit	Multiply	Metric Unit
gpm	0.0631	ℓ/sec
Btu	252	cal
ton	.0907	Mg
psig	6.894×10^3	pascal
Btu/lb	2.326×10^{-3}	MJ/kg
ft^3	0.283	m^3
mgd	157	m^3/hr
gal	3.78×10^{-3}	ft^3

APPENDIX C

Update of Case Histories*

A. Bedford Heights

The City has hired a new plant superintendent and operating crews which are 100% improvement over the manpower on duty during 1975 visit. The mechanical problems of the plant have been rectified using preventive maintenance. The effluent color during low flows was related to pickling liquor waste. The odor problems from the oxidized sludge tank were solved by fixing leaking vents. The original catalyst burner now is effective for odor controls. We suggest a revisit to this sewage treatment plant.

B. Akron, Ohio

The usual operation of this system is 24 hours a day per unit, for 7 days a week continuous; up to about 28 days. The unit is then shut down for solvent washing and equipment check. The turbine on the power recovery system drives a blower and compresses the air for activated sludge aeration.

On page 33, paragraph 2 (middle); currently spare parts are on hand for both units, eliminating the shifting of parts between units. In pargraph 3, second sentence should be expanded to say the cost of chemical conditioning of primary sludge and disposal by vacuum filtration and incineration is $86.00 per dry ton.

C. Canton, Ohio

The City of Canton has installed two (2) complete Zimpro low oxidation units rather than one (1). Near the bottom of the paragraph there is a statement, "Noticeable color to the influent." Apparently, this has cleared up; perhaps the color was due to another source.

In the last sentence of the paragraph concerning the air-water separator, please remove this statement as the separator will be removed from the building to conform to the latest Zimpro design.

D. Lucas County

On page 34, the use of the screen at the head of the grinders has eliminated the need for the grinders. Currently, the plant is near rated flow and the recycle liquor BOD is treated satisfactorily. Today the plant is located in an urban setting with large residential estates located near the site.

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* J. Robert Nicholson, Zimpro, memo to EPA, Jan. 3, 1978.

E. Columbus, Ohio (Jackson Pike)

In the middle of the first paragraph concerning operation, the current operating schedule is 85% availability, or 15% downtime for solvent washing and equipment check. The system was troubled with bits of rubber and grease, but now this is under control.

In the last sentence of the first paragraph, the odor control equipment now installed is carbon adsorption. In the second paragraph, the Columbus Southerly plant has three (3) 200 GPM operating Zimpro units that are computer controlled which do reduce the manpower required to operate the units.

F. Cambridge, Maryland

The City of Cambridge has operated the sewage plant and the Zimpro unit since 1973. The operation is now smooth with downtimes only for solvent washing and equipment check. On page 38, top of the first paragraph concerning grease content in the sludge: this is not related to the thermal conditioning plant operation. The grease is from the duck raising and slaughtering operation located on the collection system. In the middle of the first pargraph, the heat treatment operation is 16 hours a day, 5 days per week, depending upon the amount of industrial sludge. The treated and dewatered sludge is hauled approximately 16 miles as stated, which causes no problems. In the second paragraph concerning odors, this was examined quite closely and the raw sludge mixing is by diffused air which resulted in quantities of gases greater than the capacity of the fan. The fan discharges to the odor control unit. This was resolved by installing a larger fan. Please note this was a raw sludge storage tank not an oxidized tank. The plant personnel are now controlling the odors from the recycle liquor by discharging the liquor at a depth of 6 feet into the primary tank.

G. Lancaster, Pennsylvania

No comment.

H. Millville, New Jersey

To our knowledge a major overall has never been required and any downtime was due to minor maintenance and preventative maintenance program that Zimpro has established at the plant. The plant is currently operating 16 hours per day, 5 days per week. We would like to point out that although the plant is at 1/2 design capacity, all available air is being used for secondary treatment.

I. Levittown, Pennsylvania

On page 36: the unit is shutdown every 21 days for solvent washing.

J. Westchester County, New York (Rye)

Solvent washing is necessary every 300-350 hours because of the scale problem caused by sea water infiltration into an old combined collection system.

K. Rockland County, New York

On page 40 near the bottom of the paragraph concerning problems with the boiler and feed pump, air compressor and heat exchangers, the heat exchanger problems were corrected in 1974. The control of odors from the oxidized tank are satisfactory as the District did purchase the new odor control system.

L. Gloversville, New York

The sewage receives discharges from many industries, including 22 tanneries, not canneries.

M. Cincinnati, Ohio (Muddy Creek)

Add to the bottom of the paragraph: currently all sludge is tank trucked to a Zimpro unit in Mill Creek plant for processing through the Zimpro system. The unit is not operable at this time.

N. Clark County, Nevada (Las Vegas)

The Zimpro unit in Clark County has been operating since 1973. The unit currently processes primary and trickling filter humus for vacuum filtering and incineration. Treatment of supernatant and vacuum filtrate is given 14 hours of aeration prior to recycle to sewage plant.

O. Rothschild, Merrill, and Wausau, Wisconsin

No comment.

P. Terre Haute, Indiana

We have checked on the cost numbers given on page 43, and there are some reasons to question authenticity of the maintenance cost of $83.60 per ton and the excessive downtime mentioned in 1974. However, we must acknowledge that the entire sewage treatment plant (including the Zimpro unit) is in need of maintenance and repair and is certainly not even close to a representative operating unit for Zimpro.

Q. Groton, Connecticut

As of August 1977, the unit operates only when there is sufficient solids to handle or about one week per month (120 hours). The unit operates 24 hours per day until the solids are processed. The thermally conditioned sludge is dewatered using centrifuges to obtain about 50% solids in the cake without chemical additive. The cake is hauled to a landfill site, although a multiple hearth incinerator is available. The centrifuges plug up frequently and must be disassembled for cleaning, including the grinders. The lack of adequate grinding has worn out the rotors of the progressive cavity high pressure pumps. There has been a scaleup in the heat exchangers without provision to remove the scale.

R. Denton, Texas

Since the visit in 1975, the excessive amount of downtime and maintenance problems have been cleared up.